UNCLASSIFIED

AD 132012

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA, VIRGINIA

CLASSIFICATION CHANGED
TO UNCLASSIFIED
FROM CONFIDENTIAL
PER AUTHORITY LISTED IN

TAB 64-21 DATE 1 Nov. 1964

Code 23

UNCLASSIFIED

CONFIDENTIAL

NAVORD REPORT 4329

STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE U. S. NAVY 1,000 POUND LOW-DRAG BOMB AT TRANSONIC SPEEDS

5 APRIL 1957

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

CONFIDENTIAL

"This publication is [redacted] and shall be safeguarded in accordance with the security provisions of the U. S. Navy Regulations and the provisions of applicable Federal Statutes and Executive Orders for Safeguarding Classified Information. As stated in Article 0906.2 of OPNAVINST 5510.1A, dated 2 October 1954, it is forbidden to make extracts from or to copy this classified document without authorization."

[redacted]

Aeroballistic Research Report 345

STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE U. S. NAVY 1,000 POUND LOW-DRAG BOMB AT TRANSONIC SPEEDS

Prepared by:

J. E. Greene

ABSTRACT: The Magnus and static stability characteristics of a 0.214-scale model of the U. S. Navy 1,000 pound Low-Drag Bomb have been obtained from transonic wind-tunnel tests at angles of attack up to 22 degrees and for various free-stream Reynolds numbers. The variation in static aerodynamic coefficients due to roll orientation of the bomb through the range 0 - 180 degrees and drag effects due to the addition of external mounting lugs were also investigated. The tests were conducted by NOL in the Cornell Aeronautical Laboratory 4 x 3 foot transonic test facility.

The results of the test indicate that the Magnus characteristics of the bomb are linear with rotational speed and non-linear with angle of attack. Variation in the free-stream Reynolds number is seen to affect the measured Magnus characteristics appreciably at all Mach numbers and angles of attack. It is further shown that significant changes in the pitch, yaw, and roll moments may be expected to accompany variations in the roll orientation of the bomb.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

[redacted]

NAVORD Report 4329 5 April 1957

This report presents the Magnus and static stability characteristics of a 0.214-scale model of the U. S. Navy 1,000 pound Low-Drag Bomb at transonic speeds. The data were obtained in the 4 x 3 foot transonic test facility at the Cornell Aeronautical Laboratory in Buffalo, New York under task number 803-767/73003/01. Special instrumentation required to spin the model and measure dynamic forces and moments was furnished by the Naval Ordnance Laboratory.

W. W. WILBOURNE
Captain, USN
Commander

H. H. KURZWEG
By direction

Contents

Illustrations

Illustrations (Cont'd)

STATIC STABILITY AND MAGNUS CHARACTERISTICS OF THE U. S. NAVY 1,000 POUND LOW-DRAG BOMB AT TRANSONIC SPEEDS

INTRODUCTION

1. The Low-Drag Bomb family stems from an external-store design originally developed by the Douglas Aircraft Company. The bombs of the series are geometrically similar in shape but vary in weight from 250 pounds (Mk 79) to 2,000 pounds (Mk 82). For the purpose of the investigation reported herein, the 1,000 pound bomb, Mk 81, has been chosen as the representative bomb to which all test parameters have been referred.

2. During initial field evaluation and development of the Low-Drag Bomb, it was observed that on occasion the bomb would develop large pitching and yawing motions during the course of its trajectory. Subsequently it was conjectured that the cause of this somewhat erratic motion stemmed from the combined effects of the rolling motion, the pitch and yaw frequency, and the resulting yaw and Magnus moments which arise due to the roll and pitch characteristics of the bomb (reference a). In order to obtain experimental data that would help to explain such erratic missile motion as was observed, the Bureau of Ordnance directed the Naval Ordnance Laboratory to investigate the aerodynamic characteristics of the bomb.

3. As part of the subsequent Low-Drag Bomb program, NOL has conducted tests in recent months to determine the Magnus and static stability characteristics of the bomb at low-subsonic speeds ($V \leq 250$ feet per second), reference (b). More recently, NOL has tested the bomb in the Cornell Aeronautical Laboratory test facilities to determine the transonic aerodynamics of the configuration at angles of attack up to 22 degrees and Mach numbers from 0.60 to 1.25.

4. Using a 0.214-scale model of the bomb, six-component static data and Magnus force and moment characteristics were measured at spin rates scaled from the 1,000 pound bomb. The Magnus data were obtained at free-stream Reynolds numbers of 2×10^6, 4×10^6, and 6×10^6, based on model total length. Static coefficients were obtained only at a free-stream Reynolds number of 4×10^6. The figures showing static stability coefficients are presented in graphical form only for representative Mach numbers; however, a complete listing of the static coefficients for all test Mach numbers are tabulated in Appendix I.

Symbols

A maximum body cross-sectional area (sq. ft.)

C_A axial force coefficient

C_N normal force coefficient = N/qA

Symbols (Cont'd)

C_Y	side force coefficient = Y/qA
C_ℓ	rolling moment coefficient = M_ℓ/qAd
$C_{M_{c.g.}}$	pitching moment coefficient referred to the center of gravity = $M_{c.g.}/qAd$
$C_{\psi c.g.}$	yawing moment coefficient referred to the center of gravity = $M_{\psi c.g.}/qAd$
C_{Y_p}	Magnus force coefficient (side force coefficient due to spin) = $\frac{\partial Y}{\partial p} \cdot \frac{1}{qA} \cdot \frac{2V}{d}$
$C_{\psi p}$	Magnus moment coefficient (yawing moment coefficient due to spin) = $\frac{\partial M_{\psi c.g.}}{\partial p} \cdot \frac{1}{qA} \cdot \frac{2V}{d^2}$
C_{N_α}	slope of normal force coefficient through α = 0 degrees
C_{m_α}	slope of pitching moment coefficient through α = 0 degrees
d	maximum body diameter (ft.) = 1 (one) caliber
ℓ	body length (ft.)
M_ℓ	rolling moment (ft.-lbs.)
$M_{c.g.}$	pitching moment referred to the center of gravity (ft.-lbs.)
$M_{\psi c.g.}$	yawing moment referred to the center of gravity (ft.-lbs.)
D	drag force (lbs.)
N	normal force (lbs.)
Y	side force (lbs.)
p	body rotational speed (radians/sec) - positive when model is rotating clockwise as viewed from the base
q	dynamic pressure (lbs./sq.ft.)
Re	Reynolds number = $\frac{\rho V \ell}{\mu}$
V	free-stream velocity (ft./sec.)
μ	absolute coefficient of viscosity of air (lbs.-sec./ft.sq.)
ρ	air density (slugs/cu.ft.)

Symbols (Cont'd)

α angle of attack (degrees)

ψ angle of yaw (degrees)

ϕ model roll angle - positive when model is rolled clockwise as viewed from the base

Test Apparatus and Procedure

5. The tests were conducted using the Cornell Aeronautical Laboratory 4 x 3 foot transonic cart. The cart is essentially a separate test section which can be placed in the normal 10 x 12 foot wind-tunnel test section. Speeds up to about Mach number 1.25 can be obtained. Normal angle of attack range is limited to approximately $\pm$ 15 degrees. However, for angles above 15 degrees, a "dog-leg" sting adapter may be used to extend the angle of attack range in one direction. Further information on the Cornell test facility may be found in reference (c).

6. The pertinent dimensions of the bomb configuration and the details of the mounting lugs are shown in Figure 2. In order to test at angles above 20 degrees, the model length was limited to approximately 24 inches and the maximum body diameter to 3 inches. Model spin was provided by a 7 H.P. 24,000 RPM, variable frequency, water-cooled motor mounted on the forward end of a strain-gaged balance beam. The motor was internally geared to the model by a 4.2:1 reduction gear. Strain-gage leads, motor wires, and water tubes were coupled to their respective power sources by running the leads through a hollow center core in the sting. Model spin was measured by a tachometer mounted in the rear of the motor section. From the tachometer signal, the spin rate was recorded in revolutions per minute on a Berkeley EPUT counter.

7. Magnus forces and moments acting on the model were measured by means of a four-component strain-gage balance designed and manufactured by the Naval Ordnance Laboratory. Since it was desirable to obtain the variation, if any, of the stability coefficients between a "minimum" spin rate (i.e., a spin rate just sufficient to "average" the normal forces and pitching moments due to static roll orientation--approximately 30 RPM) and the maximum test spin rate of 2,000 RPM, the balance was also designed to measure normal forces and pitching moments. Both the Magnus and "static" stability characteristics were obtained up to 22 degrees angle of attack in increments of four degrees. Test procedure for the Magnus measurements was to set the model at the desired angle of attack and slowly advance the model spin to the maximum rate. The output signals of the strain-gages measuring Magnus forces and moments were suitably amplified and supplied to the pen drive on a two-channel, Leeds and Northrup, Speed-O-Max recorder. By modifying the conventional time drive of the recorder chart to include a servo-motor

driven by the model tachometer signal, it was possible to position the chart as a function of the model rotational speed and thus obtain a "trace" or record of the Magnus moment and pitching moment about each of the gage sections as a function of model spin rate for each angle of attack. However, due to the inability of the recorder chart to follow a tachometer signal corresponding to approximately 50 revolutions per minute or less, it was necessary to extrapolate the moment "traces" to zero rotational speed in order to obtain an initial slope through zero.

8. Six-component static measurements on the bomb were obtained using the CAL B-112 balance (reference d). Free-stream Reynolds number based on total model length was kept constant at 4×10^6 throughout the static measurements. Six-component data were obtained only to 22 degrees angle of attack for selected model roll positions from 0 degrees to 180 degrees.

Data Reduction

9. Within the experimental error, the Magnus moment "traces" obtained on the recorder charts were found to be linear with model rotational speed. It was sufficient, therefore, in determining coefficients, to use only the difference in the gage Magnus moment between the extrapolated zero RPM value and 2000 RPM. From this value, the Magnus coefficients, C_{Y_p} and C_{ψ_p}, were converted to non-dimensional form by the relations

$$C_{Y_p} = \frac{\partial Y}{\partial p} \cdot \frac{2V}{d} \cdot \frac{1}{qA}$$

$$C_{\psi_p} = \frac{\partial M_{\psi c.g.}}{\partial p} \cdot \frac{2V}{d^2} \cdot \frac{1}{qA}$$

Normal force, pitching moment, side force, yawing moment, roll moment, and drag were reduced to the conventional coefficient forms as shown in the section under Symbols.

Precision of Data

10. The precision of the Magnus data obtained during the test is somewhat poorer than would be desirable. Since it was necessary that the Magnus balance measure relatively small forces and moments (Magnus forces in the order of 10 percent to 20 percent of the expected normal forces), as a consequence it was also sensitive to any random model oscillations or free-stream disturbances. From previous experience, it was expected that the recorder traces would show that the model was experiencing a somewhat erratic, high frequency small amplitude oscillation. Oscillations of this type are not surprising in view of the flexible balance used and the

relatively high rotational speeds attained during the test. Past experience in similar tests has indicated that severe buffetting of the model will often occur at angles of attack above 10 to 15 degrees, depending on the spin rate and general configuration of the model. As a consequence, the "Magnus traces" consisted of "bands" whose limits were the maximum and minimum peaks of the high-frequency model oscillations. The value of the Magnus moment at any spin rate was then assumed to be the displacement of a point, on a mean line through the fluctuations, relative to any indicated moment due to static side forces which might arise at zero spin rate. Taking into account the model oscillations plus the uncertainties involved in determining the test parameters, physical measurements and reader error, the probable error in the Magnus coefficients at various angles of attack has been estimated to have the following values:

α = angle of attack	C_{Y_p}	C_{ψ_p}
4°	$\pm$ 0.32	$\pm$ 0.24
12°	$\pm$ 0.45	$\pm$ 0.49
22°	$\pm$ 1.00	$\pm$ 1.03

11. In view of the fairly large uncertainties in the Magnus data and plus the relatively small angle of attack correction indicated by a deflection load calibration, it was thought unnecessary to correct the Magnus data for pitch deflection loads at angle of attack. All the Magnus data shown in this report therefore are presented for indicated angles of attack only.

12. Uncertainties in the static data have been estimated from repeated measurements to be as follows:

C_N	$\pm$ .0046
$C_{m_{c.g.}}$	$\pm$ .0099
C_Y	$\pm$ .0033
$C_{\psi_{c.g.}}$	$\pm$ .0045
C_l	$\pm$ .0061
C_A	$\pm$ .0035

Discussion of Results

13. With the advent in recent years of reliable dynamic test techniques, it has become of increasing value to include measurements of the Magnus forces and moments in wind-tunnel development tests of spinning, fin-stabilized configurations. Unstable flights of Weapon A and the 6-inch Test Vehicle (references e and f) together with subsequent calculations and dynamic wind-tunnel measurements, have borne out the necessity for Magnus measurements and their inclusion in the method of predicting the stability performance of any spinning, fin-stabilized configuration. Accordingly, developmental wind-tunnel tests of the Low-Drag Bomb have included measurements of the Magnus forces and moments acting on the bomb, at spin rates and angles of attack comparable to those which might be expected in free-flight tests.

14. Figures 3 through 11 present the Magnus force and moment coefficients of the bomb as a function of angle of attack for various Reynolds numbers and Mach numbers. The free-stream Reynolds number was held constant at 2×10^6 and 4×10^6 (based on total model length) for two separate Mach number runs from M = 0.80 to M = 1.25, and at 6×10^6 for a third Mach number run ranging only from M = 0.60 to M = 0.95.

15. Examination of Figures 3 through 10 shows that the variation of the Magnus coefficients is, in general, non-linear with increasing angle of attack. This is markedly so for the Magnus coefficients at free-stream Reynolds numbers of 2×10^6. At this Reynolds number, the Magnus moment varies from negative values at M = 1.25 at all angles of attack, to positive values at a Mach number of M = 1.00 and below. The change in moment is due to oppositely directed Magnus forces rather than to movement of the center of pressure. At the higher free-stream Reynolds numbers of 4×10^6 and 6×10^6 the Magnus moment is positive throughout the respective range of test Mach numbers. An explanation for the "reversed" Magnus forces is not readily available. However, it has recently been observed by some experimenters (reference g) that at low subsonic speeds it is possible to generate either positive or negative Magnus forces, for example on a spinning cylinder in cross-flow, by varying the local Reynolds number around the periphery of the cylinder in such a way as to cause asymmetrical boundary-layer transition and/or separation. In this manner, the pressure distribution around the cylinder is such that the Magnus forces may act in either direction depending on the magnitude of the local Reynolds number and consequent boundary-layer separation position. It is conceivable then that the combination of the local cross-flow Reynolds number, model surface condition, and possible shock-boundary layer interaction along the model surface may set up conditions favorable to "reversed" Magnus forces such as those measured during the test. From Figures 3 through 10 it can be seen that the variation in the Magnus coefficients with Reynolds number is wide-spread. This is especially true for the higher

angles of attack. In general, it is thought that much of the suspected Reynolds number effect believed to be present in the Magnus coefficients has been obliterated by the somewhat large experimental error in the "raw" Magnus data. The small magnitude of the Magnus forces and moments together with the relatively large normal forces and pitching moments experienced by the bomb impede, to a certain extent, compatible simultaneous measurements of these forces and moments using the type of balance system necessitated by the test parameters.

16. Figure 11 indicates that the Magnus force and moment characteristics of the bomb are highly non-linear with increasing Mach number, especially in the region of $M = 1.0$ and above. It is to be noted that Figure 11 shows the Magnus force and moment coefficient only at a spin rate of 2000 RPM and for a free-stream Reynolds number of 4×10^6. However, since the Magnus data at any given angle of attack is linear with model spin rate, the data shown in Figure 11 are representative of the variation of the Magnus characteristics with Mach number for all spin rates, at least up to 2000 RPM. Note that the magnitude of the maximum Magnus moment (at $M = 0.60$) is only 15 percent of the maximum pitching moment of the bomb at 22 degrees angle of attack.

17. A previous investigation of the bomb at a Reynolds number of 6.3×10^6 and a Mach number of $M = 0.22$ (reference b) indicates that little change in the Magnus characteristics might be expected between $M = 0.60$ and $M = 0.22$.

18. Figures 12 through 19 show the normal force and pitching moment characteristics of the bomb for various roll orientations from 0 to 180 degrees. The zero degree roll position is taken to be the position of the model when the mounting lugs (Figure 2) lie in the pitch plane of the model and the fins are displaced 45 degrees from that plane. Figures 12 through 19 also show the variation of the normal force center of pressure with angle of attack for various roll positions. It is evident from examination of these data that the bomb is statically stable throughout the test Mach number range. To be noted is the expected large variation in pitching moment and normal force that occurs as the model is rolled 45 degrees from the zero roll position. In general, at 22 degrees angle of attack an average increase of 75 percent in the pitching moment coefficient occurs for a roll displacement of 45 degrees from the zero roll position at Mach numbers of $M = 0.60$ through $M = 1.25$. Similar increases in the normal force coefficients amount to approximately 10 percent at $M = 1.25$ to about 25 percent at $M = 0.60$. The center of pressure travel due to angle of attack increase is relatively small, varying less than one-half caliber at most Mach numbers.

19. Figure 20 indicates that the variation of the normal-force and pitching-moment coefficients with Mach number is generally slight for Mach numbers below approximately $M = 1.0$. An appreciable variation is noted, however, at

angles of attack above 16 degrees where a somewhat precipitate drop in the pitching-moment coefficient occurs as the Mach number is increased beyond M = 1.0. The decrease is due, however, to a forward travel in the center of pressure rather than a loss in lift.

20. Figure 21 shows a comparison of the normal-force and pitching-moment coefficient slopes, C_{N_α} and C_{m_α}, respectively, from wind-tunnel and free-flight measurements (reference g). The cross-hatched band depicts the maximum and minimum limits of the slopes due to static model roll positions of $\phi = 45^\circ$ and $\phi = 0^\circ$ respectively. As indicated on the plot, the broken curves illustrate the variation of the slopes as determined from free-flight measurements in the NOL Pressurized Ballistics Range and from wind-tunnel measurements made with the model spinning at the maximum rate of 2000 RPM. Data from these tests are considered to be somewhat less reliable than the static or free-flight data since considerable scatter was present in the coefficients at low angles of attack. These latter measurements were, of course, subject to the same disturbances as previously cited for the Magnus measurements and because of this are plotted only for a qualitative comparison with the static and free-flight slopes. As can be noted from Figure 21, the normal-force coefficient slopes from the static and free-flight data agree quite well except at the higher Mach numbers above approximately M = 1.05. The moment slopes are not in as good agreement, the free-flight data indicating less "stability" at Mach numbers in the range $0.9 \geq M \geq 1.1$ and somewhat higher "stability" in the immediate range around M = 1.0 than is indicated by the wind-tunnel data.

21. In reference to Figures 22 through 25, it is usually assumed that a cruciform finned projectile pitched at an arbitrary angle of attack will experience no side force or yawing moment as long as the fins are in a symmetrical position relative to the pitch plane. If the projectile is rolled about the longitudinal axis until the fins are no longer symmetrical relative to the pitch plane, a side force and yawing moment will appear which are dependent on the roll angle ϕ, and the magnitude of the angle of attack, α. Reference (a), in discussing the action of the yawing moment in connection with the phenomenon of so-called "catastrophic yaw," suggests that for certain special cases the yawing moment may combine with the Magnus moment and thus give rise to the occasionally-observed large pitching and yawing motions of spinning, fin-stabilized missiles.

22. Figures 22 through 25 show the variation of the side force and yawing moment coefficients with model roll angle for various angles of attack. As is evident from these data, the coefficients are roughly proportional to $\sin 4\phi$ at any arbitrary angle of attack. It is to be noted that the indicated test points on these plots have been adjusted by an amount equal to the displacement of the side force or yawing moment coefficient from the zero coefficient value at zero angle of attack for each roll position. The "uncorrected" values of the side force and yawing moment coefficients are tabulated in the Appendix. The small "trim" angles in the data at zero angle of attack were assumed to arise from misalignments of the model along the tunnel centerline and not from aerodynamic causes.

23. As previously mentioned, reference (a) suggests that for certain cases (viz., "lunar motion" or "resonance") the yawing and Magnus moments acting on a finned missile may combine when the missile is rolled at an angle such that the moments are of the same sign. It may be seen from Figures 22 through 25 that these "critical" angle ranges for the bomb apparently occur in the vicinity of $55^{\circ} \leq \phi \leq 85^{\circ}$, and $135^{\circ} \leq \phi \leq 180^{\circ}$. Note that the magnitude of the yawing moment is considerably less for $55^{\circ} \leq \phi \leq 85^{\circ}$. In this range, the mounting lugs are located in the lee-side of the model and skewed relative to the pitch plane at angles of attack. Thus, it is possible that the lugs may influence the body-shed vortices in such a manner as to introduce an interference effect which would be felt by the fins with a resultant variation in the magnitude of the yawing moment in this roll angle range.

24. In general, the yawing moment is little affected by Mach number at angles of attack of 16 degrees and below. At higher angles, however, and, in particular at model roll angles where the peak, positive yawing moments occur, t' variation of the yaw moment with Mach number is somewhat erratic and inconclusive.

25. Static rolling moment coefficients are shown in Figures 26 through 29 as a function of model angle of attack and roll orientation. As may be noted from these plots, the rolling moment coefficient is also roughly dependent on sin 4ϕ, at least for angles of attack of 16 degrees and above. The relatively constant moment experienced by the model at angles of attack of 12 degrees and below indicate that little or no induced roll effects are present at these angles.

26. The variation of the roll moment coefficient with Mach number appears to be negligible at 12 degrees angle of attack and below. At the higher angles, however, if the peak positive and negative moments are considered, the maximum moments show somewhat different characteristics. In general, it is seen that for roll angles of ϕ equal to approximately 22.5 and 112.5 degrees, the tendency of the maximum roll coefficient is to decrease with increasing Mach number from $M = 0.60$ to $M = 1.25$. For roll angles of $\phi = 67.5$ degrees and 157.5 degrees, the roll coefficient generally increases (i.e., a larger negative moment in this case) except for a small region between $M = 0.90$ to $M = 1.0$. Here, the rolling moment coefficient decreases quite rapidly, appearing almost as a discontinuity for certain angles of attack, but increasing once again beyond $M = 1.0$.

27. Figure 30 shows the variation of the spin parameter, pd/2V, as a function of angle of attack for various Mach numbers. For these tests, it was desired to obtain some idea of the equilibrium spin rate of the bomb with increasing angle of attack. By removing the motor and gearing structure the model was free to rotate, presumably somewhere near the equilibrium spin rate. Since it was not possible to determine the bearing friction in the model, Figure 30 shows only a qualitative representation of the spin history. From these data it appears that the model spin reaches a

maximum at some angle of attack around 18 - 20 degrees for the lower Mach numbers. Above M = 0.95, however, a peak is reached at somewhat lower angles. Note the fairly rapid drop in spin rate that occurs around M = 1.25.

28. Previous low-speed investigations on the Low-Drag Bomb (NOL unpublished data) have indicated that a similar "speed-up" in roll rate occurs when the bomb is subjected to angles of attack above approximately 30 degrees. Results of these tests show that the spin rate can approach values as high as four times the zero angle of attack roll rate, depending on the angle of attack. Tests are presently being carried out in the Smoke Tunnel at the University of Notre Dame in an effort to determine and subsequently control the aerodynamic mechanism governing the roll speed-up phenomenon.

29. Figure 31 presents the zero-lift drag coefficient of the bomb with and without mounting lugs attached to the bomb. For comparison, the total zero-lift drag coefficient of the bomb determined from firings of a 0.056-scale model with lugs in the NOL Pressurized Ballistics Range is also shown (reference g). It should be noted that the wind-tunnel coefficients have been adjusted to zero base drag. Accordingly, the solid curves in Figure 31 are representative of only the wave drag plus skin friction drag of the model. It may be noted from these curves that the drag coefficient shows the characteristic transonic drag rise at approximately M = 1.05 to 1.10. The increase in drag due to mounting lugs is fairly consistent throughout the Mach number range, averaging approximately 0.025 in terms of the coefficient value.

Summary

30. In summary, the results presented in this report show that the Magnus force and moment coefficients of the bomb are linearly dependent on the bomb rotational speed. It is seen that the Magnus force and moment are also dependent on the free-stream Reynolds number, in some cases being of opposite sign due to reversed Magnus forces experienced at the lower Reynolds numbers. In addition, the Magnus coefficients are seen to be generally non-linear with angle of attack and of relatively small magnitude compared to the static normal force and pitching moment coefficients.

31. The results also show the bomb to be statically stable at all angles of attack. It is seen that static normal forces and pitching moments vary appreciably with fin-roll orientation. A roll displacement of 45 degrees from the zero roll position can increase the pitching moment by approximately 75 percent and the normal force up to 25 percent. Static side forces and moments, and static rolling moments, were also found to be non-linear with increasing angle of attack. Variation of these coefficients with model roll angle is roughly proportional to sin 4ϕ for angles of attack above approximately 12 degrees. In addition, it is seen that the drag rise due

to mounting lugs is fairly small over the test Mach number range, averaging only 0.025 in terms of the coefficient value.

References

(a) Nicolaides, John D., "An Hypothesis for Catastrophic Yaw" BuOrd Ballistic Technical Note No. 18, Sept. 1955

(b) Greene, J. E., "Static Stability and Magnus Characteristics of a Low-Drag Bomb at Low Subsonic Speeds" NavOrd Report 4112 (Conf) 1956

(c) Cornell Aeronautical Laboratory, Wind-Tunnel Department Report WTO-080, 12-Foot Variable Density Wind Tunnel, May 1954

(d) Blossom, J. W., "Transonic Wind-Tunnel Tests of a 7-Caliber AN Spinner Rocket and a Low-Drag Bomb for Magnus Effects, and an Investigation of the Aerodynamic Symmetry of the Low-Drag Bomb, for the U. S. Naval Ordnance Laboratory" WTO-209 (Conf) March 1956

(e) Nicolaides, John D., "On the Flight of Ballistic Missiles" Seventh AXP Tripartite Conference (Conf) April 1956

(f) Fagin, S., Sparks, W. F., and Greene, J. E., "Summary of the NOL Investigations to Date of the Aerodynamic Forces and Moments, Including the Magnus Forces and Moments Acting on the 6" Test Vehicle and the 12.75" AS Rocket" NavOrd Report 3666 (Conf) March 1954

(g) VanAken, R. W. and Kelly, H. R., "The Magnus Force on Spinning Cylinders" IAS Preprint 712, Jan. 1957

(h) Long, J. E., "Low Yaw Data on the Low-Drag Bomb (EX-10) at Transonic Speeds ($0.7 \leq M \leq 1.4$)" NavOrd Report 4227 (Conf) Mar. 1956

TABLE I

Test Conditions

Run	Mach No.	Dynamic Pressure (lbs/ft^2) ± 1 psf	Reynolds No. ($Re \times 10^{-6}$)	Measurement	Roll Angle (ϕ -Degrees)
1	1.25	213	2	Magnus	
2	1.20	205	2	Magnus	
3	1.10	197	2	Magnus	
4	1.00	187	2	Magnus	
5	0.95	180	2	Magnus	
6	0.90	177	2	Magnus	
7	0.80	162	2	Magnus	
8	1.25	427	4	Magnus	
9	1.00	374	4	Magnus	
10	1.20	411	4	Magnus	
11	1.10	394	4	Magnus	
12	0.95	359	4	Magnus	
13	0.90	348	4	Magnus	
14	0.80	317	4	Magnus	
15	0.95	539	6	Magnus	
16	0.90	514	6	Magnus	
17	0.80	477	6	Magnus	
18	0.60	384	6	Magnus	
19	0.60	384	6	Magnus	
47	1.25	427	4	6-component static	0°
48	1.20	411	4	6-component static	0°
49	1.10	394	4	6-component static	0°
50	1.00	374	4	6-component static	0°
51	0.95	359	4	6-component static	0°
52	0.90	348	2	6-component static	0°
53	0.80	317	4	6-component static	0°

TABLE I (Cont'd)

Run	Mach No.	Dynamic Pressure $(lbs/ft^2) \pm 1$ psf	Reynolds No. $(Re \times 10^{-6})$	Measurement	Roll Angle (ϕ -Degrees)
54	0.60	251	4	6-component static	0°
55	1.25	427	4	6-component static	11.25°
56	1.00	374	4	6-component static	11.25°
57	0.90	348	4	6-component static	11.25°
58	0.60	251	4	6-component static	11.25°
59	1.25	427	4	6-component static	22.50°
60	1.10	394	4	6-component static	22.50°
61	1.00	374	4	6-component static	22.50°
62	0.90	348	4	6-component static	22.50°
63	0.60	251	4	6-component static	22.50°
64	1.25	427	4	6-component static	33.75°
65	1.00	374	4	6-component static	33.75°
66	0.90	348	4	6-component static	33.75°
67	0.60	251	4	6-component static	33.75°
68	1.25	427	4	6-component static	45.00°

TABLE I (Cont'd)

Run	Mach No.	Dynamic Pressure (lbs/ft^2) ± 1 psf	Reynolds No. ($Re \times 10^{-6}$)	Measurement	Roll Angle (ϕ -Degrees)
69	1.10	394	4	6-component static	45.00°
70	1.00	374	4	6-component static	45.00°
71	0.90	348	4	6-component static	45.00°
72	0.60	251	4	6-component static	45.00°
73	1.25	427	4	6-component static	67.50°
74	1.00	374	4	6-component static	67.50°
75	0.90	348	4	6-component static	67.50°
76	0.60	251	4	6-component static	67.50°
77	1.25	427	4	6-component static	90.00°
78	1.00	374	4	6-component static	90.00°
79	0.90	348	4	6-component static	90.00°
80	0.60	251	4	6-component static	90.00°
81	1.25	427	4	6-component static	112.50°
82	1.00	374	4	6-component static	112.50°
83	0.90	348	4	6-component static	112.50°

TABLE I (Cont'd)

Run	Mach No.	Dynamic Pressure (lbs/ft^2) ± 1 psf	Reynolds No. (Re x 10^{-6})	Measurement	Roll Angle (ϕ -Degrees)
84	0.60	251	4	6-component static	112.50°
85	1.25	427	4	6-component static	135.00°
86	1.00	374	4	6-component static	135.00°
87	0.90	348	4	6-component static	135.00°
88	0.60	251	4	6-component static	135.00°
89	1.25	427	4	6-component static	157.00°
90	1.00	374	4	6-component static	157.00°
91	0.90	348	4	6-component static	157.00°
92	0.60	251	4	6-component static	157.00°
93	1.25	427	4	6-component static	180.00°
94	1.20	411	4	6-component static	180.00°
95	1.10	394	4	6-component static	180.00°
96	1.00	374	4	6-component static	180.00°
97	0.90	348	4	6-component static	180.00°
98	0.60	251	4	6-component static	180.00°

Appendix

The Appendix lists the static coefficients obtained at a Reynolds number of 4×10^6 for various roll angles from 0 degrees to 180 degrees. Column nomenclature is listed at the top of the columns as shown on the first page of the tabulated data.

Run	Point No.	Mach No.	α	φ	ψ	C_N	$C_{M_{c.g.}}$	C_Y	$C_{\psi_{c.g.}}$	C_ℓ	C_A
47	02	1.25	8.14	.00	.00	.68354	.81387-	.02734-	.07574	.04369	.27456
47	03	1.25	12.25	.00	.00	1.07834	1.19477-	.04037-	.08026	.04472	.28425
47	04	1.25	16.39	.00	.01-	1.52290	1.39950-	.04579-	.08094	.03465	.29170
47	06	1.25	20.68	.00	.00	2.32987	1.59963-	.06009-	.15089	.00331-	.29278
47	07	1.25	.00	.00	.00	.02056	.02085-	.01929-	.06090	.01743	.25136
48	02	1.20	.01-	.00	.01-	.03397	.10553-	.00742	.07036-	.02342	.24904
48	03	1.20	8.11	.00	.02-	.72859	1.07698-	.00034-	.07701-	.03737	.26879
48	04	1.20	12.23	.00	.02-	1.13798	1.54268-	.00233-	.09488-	.03896	.28107
48	05	1.20	16.34	.00	.03-	1.58612	1.79824-	.00206-	.10314-	.02868	.28617
48	06	1.20	20.60	.00	.02-	2.26000	1.92074-	.00446-	.05873-	.00563	.28071
48	07	1.20	22.77	.00	.01	2.75101	2.00915-	.10395-	.25936	.01363	.28133
48	08	1.20	.00	.00	.01-	.03259	.10414-	.01478	.07309-	.01828	.25259
49	02	1.10	.01	.00	.00	.00429-	.09970	.00209	.01170	.03090	.24802
49	03	1.10	8.12	.00	.00	.62339	.60739-	.01588	.02828-	.03864	.25259
49	04	1.10	12.24	.00	.00	1.05648	1.18273-	.00732	.02651-	.04017	.26049
49	06	1.10	16.35	.00	.01-	1.48099	1.47355-	.00206	.06737-	.03809	.26387
49	07	1.10	20.51	.00	.02-	1.98009	1.49025-	.01811	.12007-	.01689	.27750
49	08	1.10	22.69	.00	.02-	2.47003	1.65413-	.05263	.20240-	.00152-	.27876
49	09	1.10	.01	.00	.00	.00469-	.09357	.00395	.01271	.01977	.24942
50	01	1.00	.00	.00	.00	.00423	.00368-	.00235	.00378	.01634	.11712
50	02	1.00	8.10	.00	.00	.56539	.70969-	.00219-	.00913-	.02347	.11781
50	03	1.00	12.18	.00	.01-	.99120	1.27680-	.00048	.03493-	.02796	.12152
50	04	1.00	16.27	.00	.00	1.42301	1.77137-	.00760-	.00618-	.01388	.10484
50	05	1.00	20.39	.00	.01-	1.95471	2.19375-	.00489-	.01980-	.00960	.09057
50	06	1.00	22.49	.00	.02-	2.20121	2.13364-	.00388	.11033-	.00016	.07943
50	07	1.00	.01-	.00	.03	.00471-	.00802	.00233	.00643	.01243	.11724

51	02	0.95	.01-	.00	.00	.00755-	.02263	.00809-	.01452	.03540	.09181
51	03	0.95	8.09	.00	.01-	.57249	.70417-	.01245-	.00028	.04982	.09283
51	04	0.95	12.16	.00	.01-	.94572	1.24442-	.02005-	.01165	.04497	.09092
51	05	0.95	16.23	.00	.00	1.36297	1.72336-	.02808-	.05467	.04217	.08380
51	06	0.95	20.35	.00	.02-	1.82334	2.04945-	.00049-	.09917-	.01488	.06543
51	07	0.95	22.44	.00	.03-	2.05614	2.09627-	.02859	.22911-	.01512	.05949
51	08	0.95	.00	.00	.00	.01226-	.02594	.00589-	.01283	.03532	.09300
52	01	0.90	.01-	.00	.00	.00806-	.01748	.00620-	.01341	.03330	.08783
52	02	0.90	8.09	.00	.01-	.55597	.49879-	.01063-	.00362-	.04527	.08789
52	03	0.90	12.14	.00	.01-	.92016	1.24320-	.01828-	.01029	.04341	.08788
52	04	0.90	16.22	.00	.00	1.34256	1.72016-	.03122-	.04755	.04057	.08036
52	05	0.90	20.32	.00	.02-	1.75937	2.00935-	.00385-	.07811-	.02170	.06511
52	06	0.90	22.39	.00	.03-	1.97463	2.05558-	.00919	.15033-	.01235	.05897
52	08	0.90	.00	.00	.00	.00635-	.01792	.00402-	.00894	.03015	.08857
53	02	0.80	.01-	.00	.00	.01444-	.03001	.00443-	.00975	.02864	.08441
53	03	0.80	8.07	.00	.00	.55107	.70024-	.00653-	.00765-	.04170	.08518
53	04	0.80	12.14	.00	.01-	.91044	1.22972-	.00762-	.01628-	.04330	.08676
53	05	0.80	16.18	.00	.00	1.29538	1.70136-	.03265-	.04777	.07435	.07703
53	06	0.80	20.27	.00	.01-	1.69471	2.00830-	.01922-	.00028	.02324	.06602
53	07	0.80	22.34	.00	.01-	1.88117	2.07935-	.01380-	.04078-	.02345	.06343
54	02	0.60	.01-	.00	.00	.01173-	.03341	.00884-	.01474	.03056	.07940
54	03	0.60	8.06	.00	.00	.53778	.69309-	.02912-	.03729	.04725	.08189
54	04	0.60	12.09	.00	.00	.88546	1.22072-	.02095-	.01527	.04479	.08092
54	05	0.60	16.13	.00	.00	1.26595	1.75410-	.02222-	.01971	.03714	.07206
54	06	0.60	20.18	.00	.01-	1.65035	2.12962-	.01829-	.00328-	.02079	.06659
54	07	0.60	22.23	.00	.01-	1.83477	2.29046-	.01652-	.00895-	.02108	.06257
54	08	0.60	.01-	.00	.00	.01070-	.02418	.01165-	.00094	.03484	.07781

108	02	1.20	.00	22.50	.01-	.04484	.11801-	.01880	.09198-	.02929	.21077
108	03	1.20	8.12	22.50	.03-	.75166	1.17986-	.04988	.24910-	.03663	.23577
108	04	1.20	12.20	22.50	.07-	1.18251	1.72041-	.11045	.54740-	.04274	.25367
108	05	1.20	16.33	22.50	.10-	1.64234	2.01881-	.18322	.85874-	.06611	.26429
108	06	1.20	20.59	22.50	.13-	2.40239	2.35281-	.23066	.09123-	.09568	.26742
108	07	1.20	23.13	22.50	.11-	4.17021	3.36710-	.12902	.77099-	.10394	.26400
108	08	1.20	.00	22.50	.01-	.05300	.12377-	.01465	.08876-	.02420	.21576
109	09	1.10	.00	22.50	.00	.[illegible]338	.07861	.00978	.00435-	.02554	.21942
109	10	1.10	8.12	22.50	.01-	.66683	.80364-	.04938	.17547-	.02680	.22605
109	11	1.10	12.21	22.50	.05-	1.09016	1.37641-	.12579	.52697-	.02434	.23267
109	12	1.10	16.32	22.50	.10-	1.55155	1.75118-	.21251	.94352-	.04670	.24392
109	13	1.10	20.52	22.50	.13-	2.09549	1.88745-	.26749	.17492-	.06991	.25796
109	14	1.10	22.68	22.50	.13-	2.64949	2.22785-	.27654	.22616-	.06943	.25777
109	15	1.10	.00	22.50	.00	.00332	.07855	.00974	.00431-	.02076	.21973
110	02	0.60	.01-	22.50	.00	.00349-	.01062	.01492-	.01924	.03803	.05662
110	03	0.60	8.04	22.50	.01-	.55229	.77324-	.01638	.12905-	.05134	.06131
110	04	0.60	12.08	22.50	.03-	.92455	1.40046-	.07888	.38274-	.04595	.06371
110	05	0.60	16.11	22.50	.06-	1.33513	2.04471-	.17418	.81322-	.06265	.06001
110	06	0.60	20.16	22.50	.08-	1.73938	2.49460-	.24176	.12493-	.11320	.05492
110	07	0.60	[illegible].22	22.50	.09-	1.93083	2.68695-	.26176	.21315-	.13152	.05209
110	08	0.60	.01-	22.50	.00	.01152-	.02551	.00561-	.00828	.04216	.05534

55 02	1.25	.00	11.25	.00	.01260	.00012-	.01935-	.00354	.02468	.24736
55 03	1.25	8.13	11.25	.00	.69404	.83715-	.00824	.02443-	.02614	.27657
55 04	1.25	12.25	11.25	.02-	1.11188	1.26066-	.06440	.23846-	.02037	.28682
55 05	1.25	16.39	11.25	.05-	1.56635	1.46989-	.08299	.40047-	.03677	.29360
55 07	1.25	22.17	11.25	.03-	2.72255	1.85382-	.15432	.66792-	.04326	.30042
55 08	1.25	26.66	11.25	.07-	2.32355	1.69555-	.16246	.66269-	.02630	.30311
55 09	1.25	.00	11.25	.00	.02036	.02073-	.01917-	.06046	.01499	.25336
56 02	1.00	.00	11.25	.00	.00862-	.02306	.00044	.00521	.03226	.10284
56 03	1.00	8.10	11.25	.00	.55765	.67783-	.03455	.09928-	.02610	.10803
56 04	1.00	12.17	11.25	.02-	.97520	1.27955-	.08947	.30932-	.01935	.10794
56 05	1.00	16.26	11.25	.05-	1.44119	1.84551-	.13770	.53621-	.03838	.10440
56 06	1.00	20.38	11.25	.04-	1.51014	2.21276-	.15561	.52342-	.06452	.10228
56 08	1.00	22.49	11.25	.03-	2.20501	2.25581-	.16121	.52303-	.08697	.09693
56 10	1.00	8.10	11.25	.00	.57526	.68659-	.04050	.10566-	.02039	.11653
56 11	1.00	.01-	11.25	.00	.01707-	.03459	.00034	.00271	.02368	.11455
57 01	0.90	8.08	11.25	.00	.56908	.73188-	.03550	.10015-	.02377	.09539
57 03	0.90	12.14	11.25	.02-	.94582	1.29871-	.07995	.27407-	.01626	.09356
57 04	0.90	16.21	11.25	.04-	1.36859	1.63154-	.14985	.55695-	.01811	.08813
57 05	0.90	20.32	11.25	.02-	1.78590	2.10856-	.13982	.43890-	.06212	.08678
57 06	0.90	22.39	11.25	.02-	2.01422	2.22655-	.14939	.44395-	.07129	.08189
57 07	0.90	.01	11.25	.00	.00511-	.00960	.00476	.00051-	.02114	.09621
58 02	0.60	.01-	11.25	.00	.02544-	.05245	.00256-	.00610	.03912	.07812
58 03	0.60	8.05	11.25	.00	.53925	.70133-	.02276	.08352-	.04753	.08068
58 04	0.60	12.09	11.25	.01-	.89326	1.26255-	.06369	.24275-	.03700	.08164
58 05	0.60	16.13	11.25	.03-	1.28150	1.83195-	.11692	.48568-	.04371	.07292
58 06	0.60	20.18	11.25	.05-	1.64596	2.22757-	.18623	.75093-	.06774	.06824
58 07	0.60	22.22	11.25	.04-	1.85404	2.35615-	.21168	.79656-	.07701	.06803
58 08	0.60	.01-	11.25	.00	.02381-	.05091	.01169-	.01609	.04768	.07937

59	02	1.25	.00	22.50	.00	.01869	.02047-	.03023-	.07632	.02752	.24872
59	03	1.25	8.14	22.50	.00	.70085	.86843-	.05108	.12743-	.01601	.27474
59	04	1.25	12.24	22.50	.04-	1.12465	1.39911-	.11597	.43648-	.02142	.28525
59	05	1.25	16.37	22.50	.09-	1.58950	1.64605-	.16849	.74564-	.04371	.29183
59	06	1.25	20.66	22.50	.12-	2.39952	2.02273-	.16047	.91606-	.07211	.30079
59	08	1.25	22.82	22.50	.12-	2.92761	2.22659-	.14422	.81908-	.08348	.30075
59	09	1.25	.01	22.50	.00	.01521	.01616-	.02096-	.06653	.01504	.25448
60	02	1.10	.00	22.50	.01	.01292-	.10021	.00613	.01111	.03051	.24302
60	03	1.10	8.13	22.50	.00	.65039	.72423-	.08683	.18704-	.01697	.25735
60	04	1.10	12.20	22.50	.04-	1.09159	1.36540-	.16535	.53572-	.00290	.25520
60	05	1.10	16.31	22.50	.09-	1.55394	1.61665-	.26982	.00937-	.02280	.26489
60	06	1.10	20.49	22.50	.11-	2.04954	1.90504-	.26440	.10753-	.06519	.27542
60	07	1.10	22.65	22.50	.12-	2.53715	2.08678-	.26016	.12482-	.07354	.28876
60	08	1.10	.00	22.50	.00	.00349-	.05609	.01131	.00804-	.02026	.25627
61	01	1.00	.00	22.50	.00	.00916-	.01765	.00442	.00033-	.01837	.11593
61	02	1.00	8.10	22.50	.00	.58982	.75853-	.06741	.16855-	.00921	.11833
61	03	1.00	12.17	22.50	.03-	1.02278	1.47003-	.14531	.47264-	.00696	.11865
61	06	1.00	16.24	22.50	.08-	1.46050	2.09593-	.22632	.87076-	.03505	.11032
61	07	1.00	20.37	22.50	.08-	1.95655	2.45719-	.21285	.85645-	.09383	.10409
61	08	1.00	22.48	22.50	.02-	2.28586	2.53883-	.24065	.93530-	.11665	.10190
61	09	1.00	.01-	22.50	.00	.00091-	.00047	.00847	.00604-	.01251	.11826

62	01	0.90	8.09	22.50	.00	.59238	.81740-	.06880	.17852-	.00866	.10249
62	02	0.90	12.13	22.50	.03-	.98730	1.46691-	.14377	.47683-	.00194	.10149
62	03	0.90	16.20	22.50	.07-	1.39322	1.99275-	.21873	.85580-	.03638	.09724
62	04	0.90	20.30	22.50	.07-	1.82145	2.31670-	.19909	.80210-	.09999	.09033
62	05	0.90	22.37	22.50	.08-	2.04911	2.50660-	.17967	.79319-	.11894	.08298
63	02	0.60	.01-	22.50	.00	.00519-	.01279	.00259-	.00219	.03950	.07972
63	03	0.60	8.05	22.50	.01-	.56247	.78129-	.03787	.14946-	.03934	.08117
63	04	0.60	12.08	22.50	.02-	.92544	1.40934-	.10656	.40341-	.03376	.08338
63	05	0.60	16.13	22.50	.05-	1.33882	2.07661-	.22931	.83498-	.05015	.07476
63	06	0.60	20.18	22.50	.08-	1.72246	2.32152-	.28181	.18584-	.10116	.07202
63	07	0.60	22.21	22.50	.08-	1.90887	2.71211-	.28031	.22981-	.13238	.06778
63	08	0.60	.00	22.50	.00	.00925-	.02373	.01798-	.01776	.04361	.07826

64	02	1.25	.01-	33.75	.00	.01303	.00098-	.02301-	.07102	.02474	.24505
64	03	1.25	8.14	33.75	.00	.73305	1.00299-	.04291	.09855-	.01875	.27442
64	04	1.25	12.24	33.75	.04-	1.16085	1.56399-	.13116	.46534-	.01418	.28693
64	05	1.25	16.38	33.75	.10-	1.65266	1.69712-	.22496	.91166-	.03213	.29442
64	06	1.25	20.64	33.75	.13-	2.49397	2.35773-	.24770	.10400-	.06053	.30013
64	07	1.25	22.85	33.75	.12-	3.03738	2.57726-	.15267	.60213-	.07622	.29254
64	08	1.25	.00	33.75	.01	.01653	.00907-	.02268-	.07271	.01475	.25049
65	0[illegible]	1.00	.01-	33.75	.00	.01370-	.02723	.00661	.00465-	.02938	.10834
65	03	1.00	8.09	33.75	.00	.62249	.65597-	.05925	.15684-	.01802	.11537
65	04	1.00	12.17	33.75	.03-	1.07043	1.05001-	.13910	.47204-	.01228	.11727
65	05	1.00	16.25	33.75	.07-	1.60114	2.01490-	.25222	.91675-	.03545	.10697
65	06	1.00	20.35	33.75	.07-	2.09385	3.02087-	.27203	.05989-	.08266	.08916
65	07	1.00	22.44	33.75	.10-	2.38857	3.22215-	.20716	.93964-	.10514	.07420
65	08	1.00	.01-	33.75	.00	.01315-	.02618	.00236	.00117	.02074	.11170
66	01	0.90	.01-	33.75	.00	.00947-	.01914	.00247	.00156-	.01772	.09178
66	02	0.90	8.08	33.75	.01-	.60397	.36516-	.05503	.15513-	.00367	.09841
66	03	0.90	12.13	33.75	.03-	1.04203	1.66974-	.15051	.49216-	.00545	.09982
66	04	0.90	16.20	33.75	.07-	1.43024	2.28298-	.26151	.00489-	.04008	.09761
66	05	0.90	20.29	33.75	.09-	1.92354	2.75355-	.28372	.07684-	.09138	.08753
66	06	0.90	22.35	33.75	.09-	2.16183	2.95512-	.22792	.97479-	.12248	.07411
67	02	0.60	.01-	33.75	.00	.01154-	.02541	.00565-	.00842	.03942	.07991
67	03	0.60	8.05	33.75	.01-	.58162	.34595-	.04415	.15399-	.03955	.08411
67	04	0.60	12.09	33.75	.02-	.98406	1.60155-	.13437	.44718-	.03429	.08814
67	05	0.60	16.11	33.75	.05-	1.40229	2.36453-	.26562	.95952-	.04266	.08494
67	06	0.60	20.16	33.75	.07-	1.82049	2.93525-	.38935	.48455-	.09438	.07864
67	07	0.60	22.20	33.75	.09-	2.04174	3.19404-	.41916	.59435-	.11709	.07435
67	08	0.60	.01-	33.75	.00	.00414-	.01173	.00664-	.01064	.04795	.07716

68	01	1.25	.00	45.00	.01	.01655	.00377-	.02116-	.07190	.02474	.24530
68	02	1.25	8.14	45.00	.01	.74864	1.34644-	.03611	.02723-	.01650	.27778
68	03	1.25	12.24	45.00	.01-	1.20791	1.65010-	.07685	.20931-	.01616	.29294
68	04	1.25	16.56	45.00	.04-	1.71057	2.11862-	.11500	.65177-	.00525	.29625
68	05	1.25	20.63	45.00	.06-	2.55074	2.62772-	.15540	.99546-	.00454	.29450
68	06	1.25	22.83	45.00	.07-	3.07342	2.82155-	.15113	.56557-	.01806	.28438
68	07	1.25	.00	45.00	.01	.02775	.02214-	.02293-	.07271	.01468	.24970
69	02	1.10	.00	45.00	.01	.00559-	.10054	.00737	.00972	.02509	.24516
69	03	1.10	8.13	45.00	.01	.70771	.99903-	.05062	.05345-	.01672	.25623
69	04	1.10	12.21	45.00	.01	1.19088	1.72407-	.11560	.23025-	.01100	.26587
69	05	1.10	16.30	45.00	.02-	1.69543	2.54314-	.23377	.60203-	.00486	.27115
69	06	1.10	20.47	45.00	.07-	2.27366	2.70506-	.34955	.06536-	.02187	.28921
69	07	1.10	22.62	45.00	.05-	2.70737	3.01477-	.22061	.74626-	.03365	.28227
69	08	1.10	.00	45.00	.01	.01042-	.13624	.00942	.01075	.01682	.24980
70	01	1.00	.01-	45.00	.00	.01415-	.03330	.00640	.00705-	.01507	.11332
70	02	1.00	8.10	45.00	.01	.53622	.39511-	.04968	.06418-	.00697	.11852
70	03	1.00	12.15	45.00	.00	1.12046	1.79748-	.10896	.22892-	.00316-	.12289
70	04	1.00	16.22	45.00	.01-	1.65284	2.75993-	.21523	.55602-	.00970-	.11390
70	05	1.00	20.33	45.00	.04-	2.21431	3.33863-	.30095	.86955-	.01170	.09093
70	06	1.00	22.42	45.00	.05-	2.54717	3.72264-	.26363	.84738-	.02224	.06981
70	07	1.00	.01-	45.00	.00	.00465-	.01495	.00423	.00540-	.00960	.11811

71	02	0.90	.01-	45.00	.00	.00135	.00036-	.00136-	.00114-	.03036	.08921
71	04	0.90	8.09	45.00	.00	.64098	.95021-	.02955	.05641-	.04088	.09535
71	05	0.90	12.13	45.00	.00	1.10893	1.85535-	.10610	.23771-	.01371	.09899
71	06	0.90	16.19	45.00	.05-	1.61593	2.79935-	.24313	.69175-	.01584	.09425
71	07	0.90	20.22	45.00	.06-	2.11670	3.41394-	.36533	.13419-	.05669	.08142
71	08	0.90	22.34	45.00	.07-	2.35322	3.61510-	.34835	.13545-	.08151	.06633
71	09	0.90	.00	45.00	.00	.00095	.00594	.00196-	.00104-	.02406	.09109
72	02	0.60	.00	45.00	.00	.00442-	.02086	.00877-	.00687	.04374	.07739
72	03	0.60	8.05	45.00	.00	.61503	.91327-	.02318	.06054-	.03932	.08474
72	04	0.60	12.08	45.00	.00	1.03404	1.72221-	.08077	.22711-	.03375	.09145
72	05	0.60	16.11	45.00	.02-	1.51108	2.65539-	.21049	.62145-	.03254	.08418
72	06	0.60	20.16	45.00	.06-	2.01110	3.56734-	.41245	.36112-	.05466	.07789
72	07	0.60	22.18	45.00	.07-	2.25186	3.98264-	.48133	.52426-	.06508	.07176
72	08	0.60	.01-	45.00	.00	.00401	.00627	.01803-	.01305	.04818	.07719

73	02	1.25	.00	67.50	.01	.01896	.00555-	[illegible]	.06767	.01976	.24833
73	03	1.25	8.16	67.50	.03	.71991	.65967-	.01635-	.23556	.02612	.27944
73	04	1.25	12.25	67.50	.07	1.10540	1.35721-	.04565-	.37699	.01029-	.29030
73	05	1.25	16.40	67.50	.05	1.71244	1.85000-	.00240	.19761	.05927-	.29260
73	07	1.25	20.67	67.50	.03	2.40345	[illegible]	.00876	.17978	.08619-	.29355
73	08	1.25	22.61	67.50	.08	1.90590	2.19519-	.04138-	.43209	.07432-	.29035
73	09	1.25	.00	67.50	.01	.03073	.03073-	.02113-	.03291	.00965	.25552
74	02	1.00	.01-	67.50	.00	.00584	.00040-	.00040	.00002	.02977	.10992
74	03	1.00	8.11	67.50	.02	.65337	.80522-	.01144-	.13882	.01990	.11801
74	04	1.00	12.17	67.50	.03	1.05129	1.47612-	.02363-	.33544	.00570	.12078
74	05	1.00	16.29	67.50	.07	1.61631	2.29002-	.00637	.32707	.01849-	.10587
74	06	1.00	20.40	67.50	.09	[illegible]	2.59526-	.07149	.27639	.03384-	.08451
74	07	1.00	22.46	67.50	.09	2.47384	3.00211-	.08714	.24821	.05256-	.07118
74	08	1.00	.01-	67.50	.00	.00851	.01688-	.00597	.01135-	.02401	.11573
75	02	0.90	.00	67.50	.00	.00060	.00027-	.00040	.00005-	.03041	.06928
75	03	0.90	8.11	67.50	.02	.62077	.81419-	.01555-	.16311	.02617	.09751
75	04	0.90	12.14	67.50	.05	1.02920	1.45409-	.04267-	.36579	.00775	.09978
75	05	0.90	16.22	67.50	.06	1.55086	2.27435-	.01645	[illegible]	.01463-	.08800
75	06	0.90	20.34	67.50	.08	2.04551	2.82537-	.13522	.09739	.05271-	.06697
75	07	0.90	22.38	67.50	.06	2.29066	3.00509-	.17724	.00034	.05921-	.05680
75	08	0.90	.01-	67.50	.00	.00075	.00031-	.00036	.00201-	.02727	.09121
76	02	0.60	.00	67.50	.00	.01395-	.02525	.00391-	.00732	.03073	.07966
76	03	0.60	8.04	67.50	.01	.58355	.77429-	.02823-	.15716	.03395	.08870
76	04	0.60	12.10	67.50	.03	.95561	1.39541-	.05200-	.35855	.01789	.09469
76	05	0.60	16.13	67.50	.05	1.41047	2.14250-	.03455-	.40753	.00583	.08497
76	06	0.60	20.17	67.50	.06	1.91570	2.91536-	.02014	.40319	.01230-	.06406
76	07	0.60	22.22	67.50	.07	2.12180	3.52405-	.02296	.45152	.01227-	.05566

77	02	1.25	.00	90.00	.01	.01851	.00007	.01405-	.06430	.01748	.25348
77	03	1.25	6.14	90.00	.02	.68389	.71752-	.00057-	.06582	.02306	.27967
77	04	1.25	12.26	90.00	.02	1.11546	1.12145-	.04186	.01868-	.00863	.29236
77	05	1.25	16.43	90.00	.02	1.63315	1.70312-	.12777	.18565-	.02216-	.29875
77	06	1.25	20.70	90.00	.03	2.42593	1.64315-	.18222	.28857-	.02144-	.29752
77	07	1.25	22.90	90.00	.02	2.92582	1.76356-	.18345	.29644-	.00565	.29305
77	08	1.25	.00	90.00	.01	.02261	.00911-	.01947-	.07475	.01259	.25824
78	02	1.00	.01-	90.00	.00	.00425	.00300-	.00259	.00410-	.02692	.11116
78	03	1.00	6.10	90.00	.01	.57709	.59952-	.00187	.02416	.02554	.11209
78	04	1.00	12.19	90.00	.01	.99637	1.11520-	.04139	.03247-	.01189	.11665
78	05	1.00	16.29	90.00	.02	1.46951	1.61806-	.11688	.16596-	.00319	.10881
78	07	1.00	20.42	90.00	.02	2.04436	2.09211-	.20356	.36044-	.00279	.09573
78	09	1.00	22.55	90.00	.02	2.33565	2.08222-	.23490	.45465-	.02539	.08915
78	10	1.00	.00	90.00	.00	.00000	.00017	.00433	.00550-	.01541	.11653
79	02	0.90	.02-	90.00	.00	.00085	.00624-	.00044	.00009-	.03361	.08914
79	03	0.90	6.08	90.00	.01	.57172	.62352-	.00196-	.03475	.03261	.09483
79	04	0.90	12.16	90.00	.01	.96951	1.14151-	.01860	.02121	.02082	.09579
79	05	0.90	16.24	90.00	.02	1.41314	1.62233-	.08520	.10843-	.01480	.08744
79	06	0.90	20.37	90.00	.02	1.90983	2.00068-	.17045	.30333-	.01790	.07837
79	07	0.90	22.44	90.00	.03	2.16053	2.06139-	.15667	.29672-	.03617	.07579
79	08	0.90	.01-	90.00	.00	.00052	.00016	.00257	.00446-	.02755	.09617
80	02	0.60	.01-	90.00	.00	.01083-	.02532	.00880-	.00692	.03936	.07768
80	03	0.60	6.04	90.00	.00	.53740	.60965-	.01708-	.04360	.04258	.08241
80	04	0.60	12.11	90.00	.00	.90125	1.12142-	.00305	.00077	.03146	.08414
80	05	0.60	16.13	90.00	.00	1.29971	1.65591-	.03541	.06312-	.03276	.07870
80	06	0.60	20.20	90.00	.00	1.70750	2.10125-	.10666	.23071-	.03404	.07514
80	07	0.60	22.23	90.00	.00	1.91375	2.24060-	.12996	.23755-	.04283	.06796
80	08	0.60	.02-	90.00	.00	.00410-	.01195	.00879-	.00689	.03938	.07807

81	02	1.25	.01	112.50	.01	.02232	.01260	.01778-	.05475	.02000	.25339
81	04	1.25	12.28	112.50	.05-	1.15277	1.33132-	.10563	.45067-	.03235	.29709
81	05	1.25	16.41	112.50	.09-	1.64135	1.62235-	.22067	.89042-	.06783	.30637
81	06	1.25	20.66	112.50	.12-	2.42009	1.90961-	.24763	.04754-	.07271	.31247
81	07	1.25	22.88	112.50	.12-	3.01145	2.17506-	.22012	.98065-	.09679	.30736
81	08	1.25	9.14	112.50	.01-	.70971	.82044-	.02728	.10261-	.01936	.28763
81	09	1.25	.01	112.50	.01	.02581	.00033-	.01585-	.06525	.01521	.25939
82	02	1.00	.01-	112.50	.00	.00503	.00827-	.00449	.01093-	.02989	.11095
82	03	1.00	5.10	112.50	.02-	.61067	.73662-	.03840	.16305-	.02992	.11565
82	04	1.00	12.20	112.50	.05-	1.05195	1.42954-	.13495	.52697-	.03585	.11853
82	06	1.00	16.26	112.50	.09-	1.52948	2.01097-	.24562	.96288-	.07067	.11944
82	07	1.00	20.33	112.50	.08-	2.00071	2.43194-	.27202	.99655-	.12919	.11260
82	08	1.00	22.50	112.50	.08-	2.35505	2.59540-	.28871	.01898-	.16065	.10147
82	09	1.00	.01-	112.50	.00	.00844	.01683-	.00852	.01131-	.02095	.11106
83	01	0.90	.01-	112.50	.00	.01003	.01928-	.00246	.00438-	.01807	.09441
83	02	0.90	5.06	112.50	.02-	.59452	.75842-	.02837	.14579-	.02462	.10030
83	03	0.90	12.15	112.50	.05-	1.01873	1.42508-	.11691	.50035-	.03106	.10635
83	04	0.90	16.21	112.50	.09-	1.44166	1.93955-	.22168	.95225-	.07825	.10670
83	05	0.90	20.33	112.50	.07-	1.88905	2.24370-	.18495	.79617-	.16003	.10003
83	06	0.90	22.41	112.50	.07-	2.17540	2.53115-	.17996	.75471-	.18199	.09122
83	07	0.90	.02-	112.50	.00	.01546	.02965-	.00199-	.00180	.01600	.09384
84	02	0.80	.01-	112.50	.00	.00425-	.01186	.00890-	.00700	.03088	.08072
84	03	0.80	6.05	112.50	.01-	.56409	.73021-	.01579	.14048-	.03545	.08734
84	04	0.80	12.08	112.50	.03-	.92958	1.34255-	.08403	.41091-	.04334	.09271
84	05	0.80	16.12	112.50	.06-	1.34701	2.01067-	.20721	.89132-	.06902	.09561
84	06	0.80	20.17	112.50	.09-	1.75197	2.55434-	.26355	.23181-	.14665	.08967
84	07	0.80	22.22	112.50	.09-	1.99600	2.92266-	.22366	.11139-	.18640	.08748
84	08	0.80	.01-	112.50	.00	.00361-	.01146	.01193-	.00929	.03508	.07975

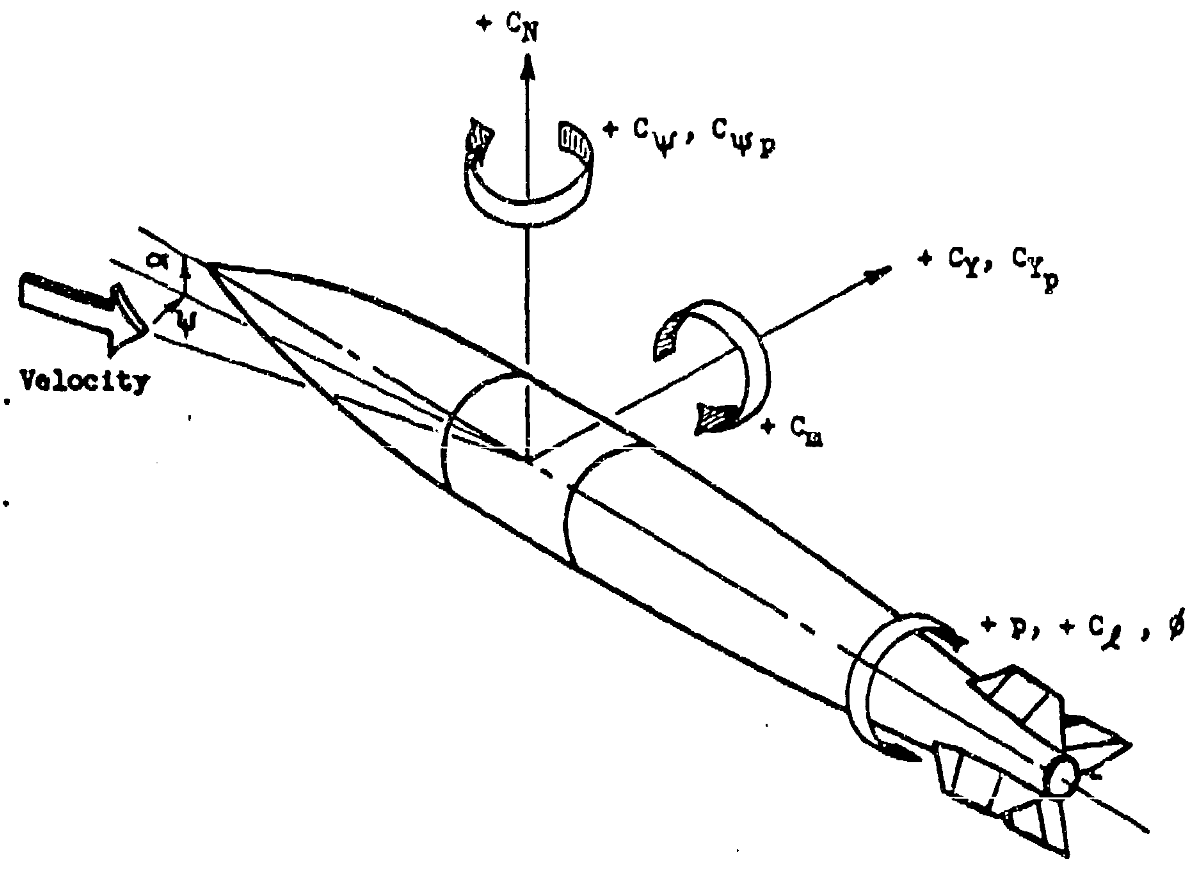
65	03	1.25	.00	135.00	.00	.02795	.00310	.02854-	.07726	.02485	.24972
65	04	1.25	8.13	135.00	.01-	.72985	.97307-	.00940-	.00412-	.03728	.28598
65	05	1.25	12.25	135.00	.01-	1.20144	1.61444-	.01020	.07635-	.03453	.30174
65	06	1.25	16.38	135.00	.03-	1.75261	2.13924-	.04937	.25590-	.03570	.30730
65	07	1.25	20.66	135.00	.04-	2.61112	2.75857-	.04151	.25379-	.02209	.30195
65	08	1.25	22.84	135.00	.04-	3.12583	2.93396-	.0[illegible]43-	.13790-	.04535	.29377
65	09	1.25	.01	135.00	.00	.03845	.00685-	.02477-	.06464	.01741	.25357
66	03	1.00	.01-	135.00	.00	.00079	.00045-	.00036	.00006	.02682	.11043
66	04	1.00	8.08	135.00	.01-	.62776	.89448-	.01245	.07737-	.03615	.12033
66	05	1.00	12.15	135.00	.02-	1.11615	1.79236-	.03016	.14004-	.03857	.12680
66	06	1.00	16.22	135.00	.03-	1.65506	2.72394-	.06551	.29452-	.05219	.11952
66	[illegible]	1.00	20.35	135.00	.05-	2.26015	3.49855-	.10150	.44374-	.06428	.10084
66	09	1.00	22.44	135.00	.06-	2.59765	3.78564-	.09461-	.07300-	.05196	.08241
66	10	1.00	.01-	135.00	.00	.00529	.00922-	.00026	.00241-	.02132	.11858
67	01	0.90	.01-	135.00	.00	.00593	.01626-	.00028	.00275-	.02132	.09547
67	02	0.90	8.07	135.00	.01-	.62467	.92854-	.00925	.07475-	.02641	.10784
67	03	0.90	12.13	135.00	.02-	1.09000	1.84990-	.02219	.13520-	.03744	.11255
67	04	0.90	16.18	135.00	.03-	1.60123	2.77673-	.04532	.27109-	.04914	.10630
67	05	0.90	20.26	135.00	.03-	2.12612	3.61110-	.00404-	.12455-	.06139	.08535
67	06	0.90	22.32	135.00	.01-	2.39214	3.85113-	.06477-	.07641	.05392	.07650
67	07	0.90	.01-	135.00	.00	.00548	.01600-	.00249	.00437-	.01858	.09980
68	02	0.60	.00	135.00	.00	.00591	.01449-	.00585-	.00467	.02649	.07970
68	04	0.60	8.05	135.00	.01-	.59832	.89929-	.00466-	.05115-	.03979	.08803
68	05	0.60	12.07	135.00	.01-	1.02050	1.73641-	.01021	.11503-	.03891	.09741
68	06	0.60	16.10	135.00	.02-	1.48945	2.63177-	.03390	.23622-	.05051	.09439
68	07	0.60	20.14	135.00	.03-	1.96844	3.53455-	.04536	.32279-	.06564	.08021
68	08	0.60	22.16	135.00	.03-	2.23184	3.95943-	.00261	.18960-	.07470	.07188
68	09	0.60	.01-	135.00	.00	.00277	.00219-	.01196-	.01318	.03059	.07771

89	02	1.25	.00	157.50	.00	.02395	.00254	.02149-	.05842	.02007	.25363
89	03	1.25	8.16	157.50	.01	.71737	.87862-	.05052-	.14569	.03875	.28338
89	04	1.25	12.25	157.50	.04	1.13639	1.37752-	.11768-	.45845	.02882	.29917
89	05	1.25	16.39	157.50	.06	1.64922	1.75240-	.19358-	.75816	.01389-	.30520
89	06	1.25	20.66	157.50	.09	2.49842	2.23375-	.21761-	.86570	.05885-	.30380
89	07	1.25	22.48	157.50	.09	2.95765	2.44716-	.20883-	.82812	.07498-	.29786
89	08	1.25	.01	157.50	.00	.03166	.01264-	.02136-	.05355	.01525	.25842
90	02	1.00	.01-	157.50	.00	.00562	.00307-	.00251	.00159-	.03264	.10943
90	03	1.00	8.08	157.50	.00	.60872	.82828-	.01589-	.03519	.03796	.11333
90	04	1.00	12.16	157.50	.03	1.01997	1.46515-	.08892-	.35744	.03500	.11734
90	05	1.00	16.24	157.50	.07	1.48935	2.07524-	.17696-	.73434	.00777	.11328
90	06	1.00	20.39	157.50	.07	1.97287	2.39077-	.17906-	.73277	.04522-	.09744
90	08	1.00	22.47	157.50	.07	2.31135	2.59322-	.18129-	.75891	.06063-	.08695
90	09	1.00	.01-	157.50	.00	.00469	.01478-	.00445	.00301-	.02102	.11352
91	01	0.90	.01-	157.50	.00	.01032	.01972-	.00028	.00007	.02125	.09514
91	02	0.90	8.09	157.50	.00	.51536	.37827-	.02562-	.06695	.03329	.09917
91	03	0.90	12.16	157.50	.03	1.00026	1.49759-	.11131-	.42694	.02715	.10477
91	04	0.90	16.20	157.50	.06	1.38371	1.69033-	.17440-	.71021	.01779-	.10286
91	05	0.90	20.30	157.50	.06	1.81934	2.21646-	.15783-	.55676	.05469-	.09154
91	06	0.90	22.38	157.50	.06	2.09685	2.45162-	.16395-	.65302	.07773-	.07735
91	08	0.90	.01-	157.50	.00	.01537	.02982-	.00191-	.00455	.02126	.09624
92	02	0.60	.01-	157.50	.00	.00189	.00107-	.00578-	.00462	.03087	.08064
92	03	0.60	8.07	157.50	.00	.56243	.79570-	.04714-	.10568	.04322	.08593
92	04	0.60	12.08	157.50	.02	.92931	1.42419-	.11650-	.39464	.04597	.09058
92	05	0.60	16.12	157.50	.04	1.34786	2.07685-	.20920-	.76350	.02653	.08930
92	07	0.60	20.16	157.50	.07	1.78474	2.67420-	.29133-	.17428	.00500-	.07869
92	08	0.60	22.21	157.50	.06	2.01969	2.99481-	.32451-	.31296	.01642-	.07056
92	09	0.60	.01-	157.50	.00	.00306	.00186-	.01195-	.00927	.03503	.07618

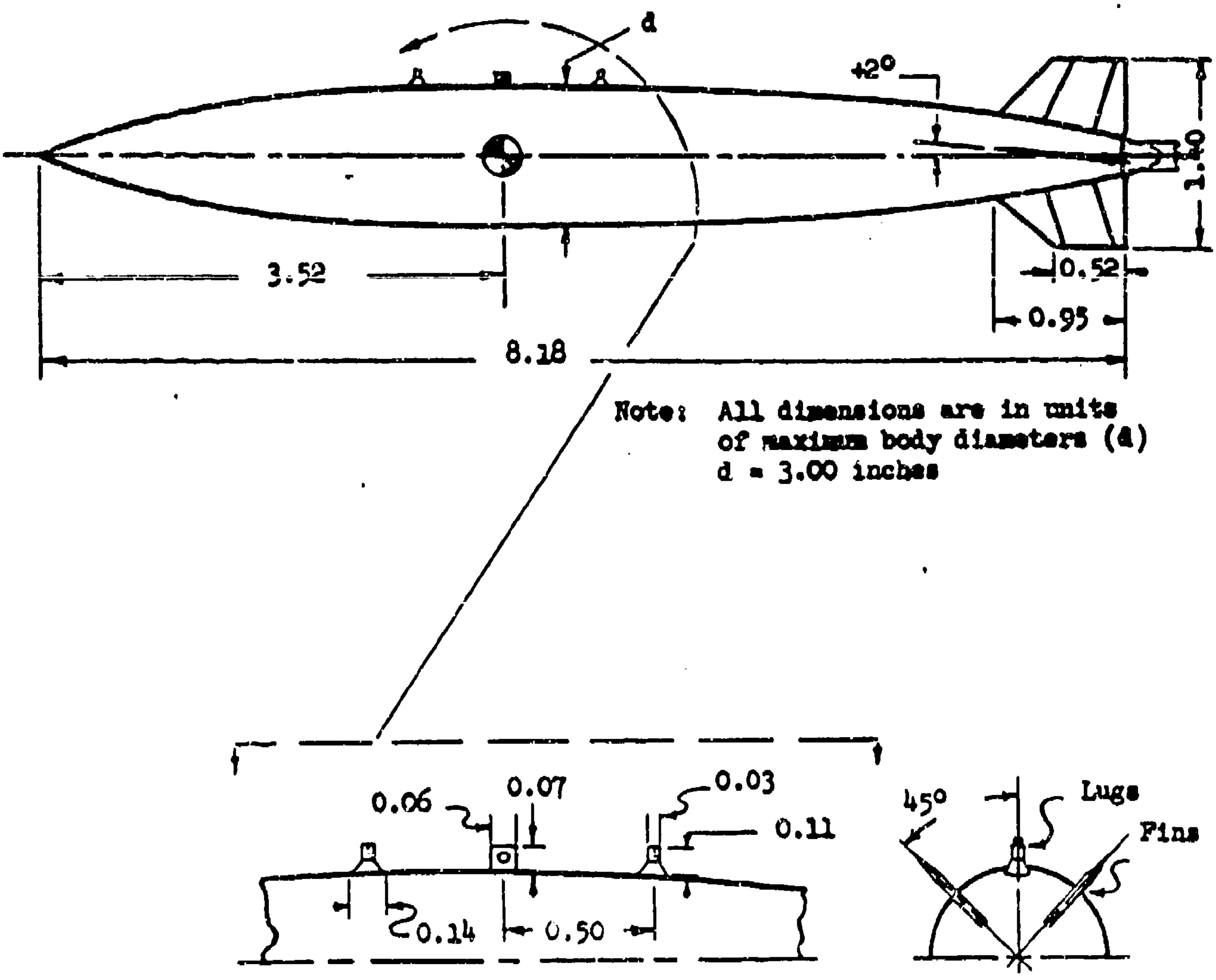
93	02	1.25	.00	180.00	.00	.02287	.00633	.04150-	.04666	.02011	.25496
93	03	1.25	6.16	180.00	.00	.68552	.74905-	.02512-	.07175	.03627	.27747
93	04	1.25	12.27	180.00	.00	1.09741	1.16898-	.04024-	.08840	.03419	.28799
93	05	1.25	16.40	180.00	.00	1.58626	1.41893-	.04397-	.10352	.02155	.29470
93	06	1.25	20.70	180.00	.00	2.41425	1.77779-	.04029-	.07365	.00260-	.29217
93	08	1.25	.00	180.00	.00	.03092	.01114-	.01590-	.03761	.01274	.25779
94	02	1.20	.00	180.00	.01-	.04520	.09803-	.01110	.08381-	.02366	.25104
94	03	1.20	3.11	180.00	.02-	.72065	1.00015-	.01070	.10102-	.04049	.27173
94	04	1.20	12.22	180.00	.02-	1.13578	1.46865-	.01246	.11490-	.03681	.28579
94	05	1.20	16.38	180.00	.02-	1.61603	1.75917-	.01633	.13028-	.02630	.29057
94	06	1.20	20.60	180.00	.02-	2.35745	2.09245-	.00254-	.07534-	.01928	.28353
94	07	1.20	22.78	180.00	.01-	2.68844	2.32879-	.03633-	.03693	.01740	.27671
94	08	1.20	.00	180.00	.01-	.04455	.10223-	.01475	.08845-	.01848	.25441
95	01	1.10	.00	180.00	.00	.00429	.36722	.00787	.00275-	.02021	.25513
95	02	1.10	6.15	180.00	.00	.64099	.55263-	.01475	.03614-	.03083	.26043
95	03	1.10	12.22	180.00	.00	1.03960	1.14180-	.00445-	.00022	.03214	.26745
95	04	1.10	16.35	180.00	.01-	1.52897	1.54400-	.01574	.05560-	.02472	.27474
95	05	1.10	20.52	180.00	.02-	2.07460	1.63857-	.03554	.15651-	.01340	.28051
95	06	1.10	22.66	180.00	.02-	2.51735	1.72527-	.05477	.20966-	.00411	.28000
95	07	1.10	.00	180.00	.00	.00342	.07734	.00778	.00227	.01464	.25603

96	02	1.00	.01-	180.00	.00	.00339-	.00262	.00042	.00001	.02972	.10902
96	03	1.00	8.09	180.00	.00	.58273	.70708-	.00417	.02449-	.04054	.10754
96	04	1.00	12.16	180.00	.01-	.96525	1.25474-	.00077	.03275-	.03584	.10430
96	05	1.00	16.27	180.00	.00	1.43327	1.80983-	.00695	.03281-	.02747	.10037
96	06	1.00	20.40	180.00	.01-	1.96050	2.14153-	.00498	.05332-	.01523	.08336
96	07	1.00	22.45	180.00	.02-	2.22520	2.20475-	.03287	.16111-	.00675	.07626
96	08	1.00	.01-	180.00	.00	.00079	.00043-	.00036	.00006	.02673	.10992
97	02	0.90	.01-	180.00	.00	.00580	.01056-	.00189-	.00454	.02432	.09298
97	03	0.90	8.08	180.00	.00	.56144	.71662-	.00399-	.00585-	.03594	.08806
97	04	0.90	12.13	180.00	.00	.94211	1.27053-	.00143	.02152-	.03103	.09014
97	05	0.90	16.21	180.00	.00	1.35033	1.74195-	.00696-	.00369	.02838	.08414
97	06	0.90	20.33	180.00	.01-	1.78813	1.95924-	.01796	.10314-	.00951	.07483
97	07	0.90	22.40	180.00	.02-	2.00063	2.03052-	.05069	.24068-	.00326	.06764
97	08	0.90	.00	180.00	.00	.00015	.00027-	.00260	.00112	.02431	.09404
98	02	0.60	.01-	180.00	.00	.00404	.00297-	.01805-	.01779	.03953	.07933
98	03	0.60	8.04	180.00	.00	.54390	.71296-	.01366-	.00999	.05591	.07738
98	04	0.60	12.06	180.00	.00	.88621	1.22073-	.01167-	.00347-	.05370	.08125
98	05	0.60	16.14	180.00	.00	1.27441	1.74477-	.01615-	.01116	.04615	.07518
98	06	0.60	20.18	180.00	.01-	1.60113	2.14495-	.01219-	.01577-	.02978	.07052
98	07	0.60	22.23	180.00	.01-	1.86845	2.26739-	.01063	.06859-	.02545	.06293
98	08	0.60	.00	180.00	.00	.00245	.00164-	.00671-	.01069	.04376	.07591

Coordinate Axes and Sign Convention

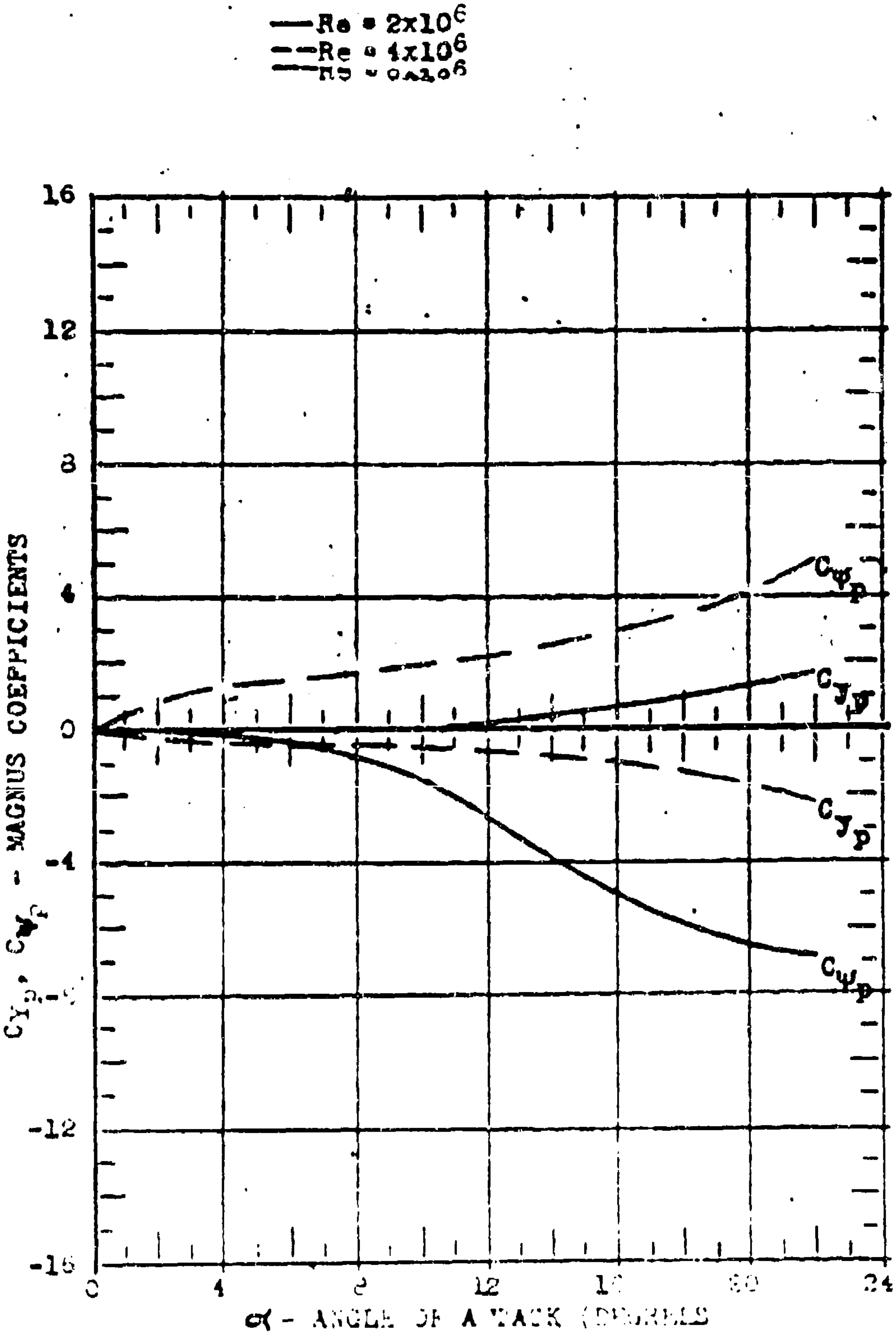


0.214-Scale Model of the U. S. Navy
1000 lb Mk 81 Low-Drag Bomb



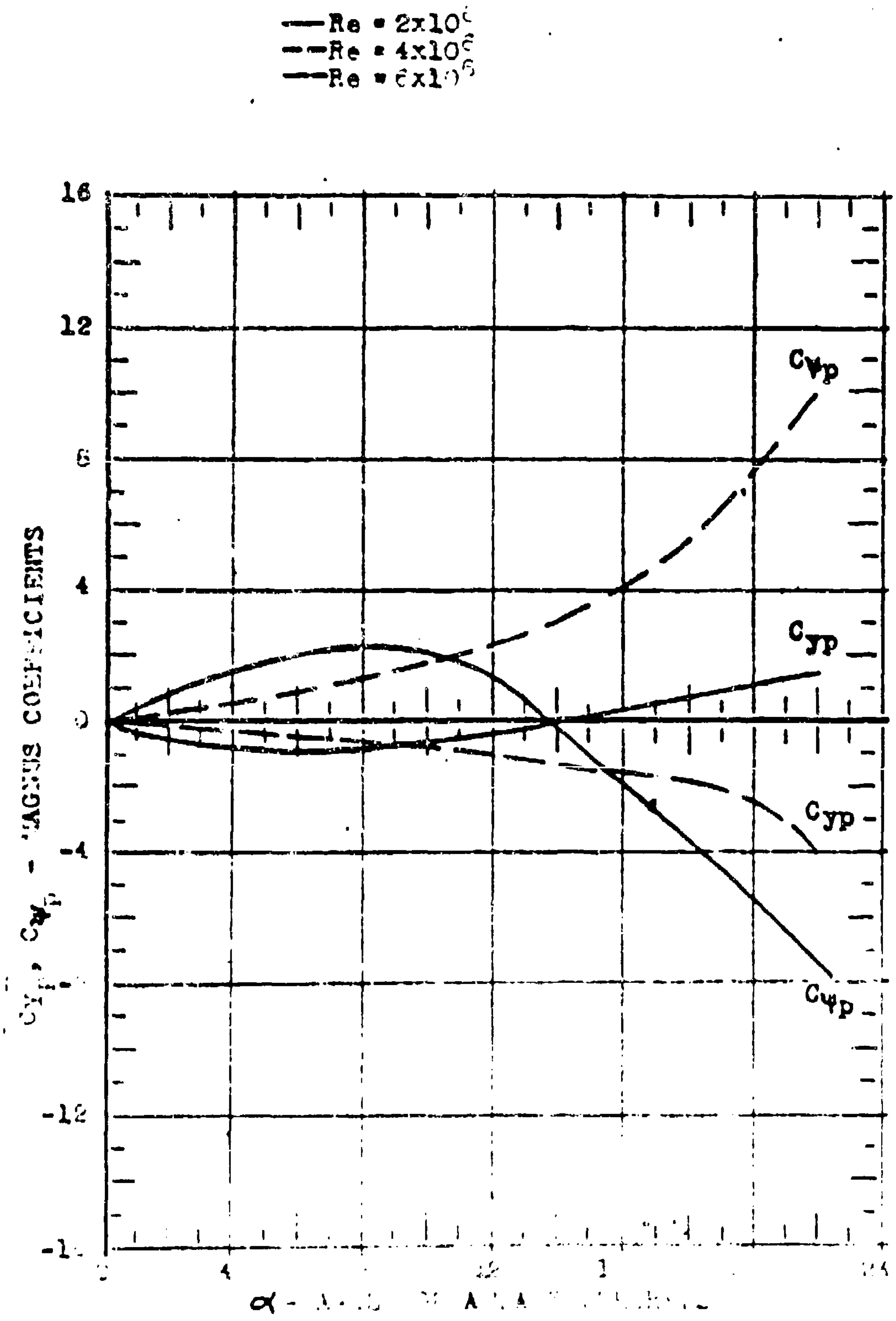
VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

$M = 1.25$



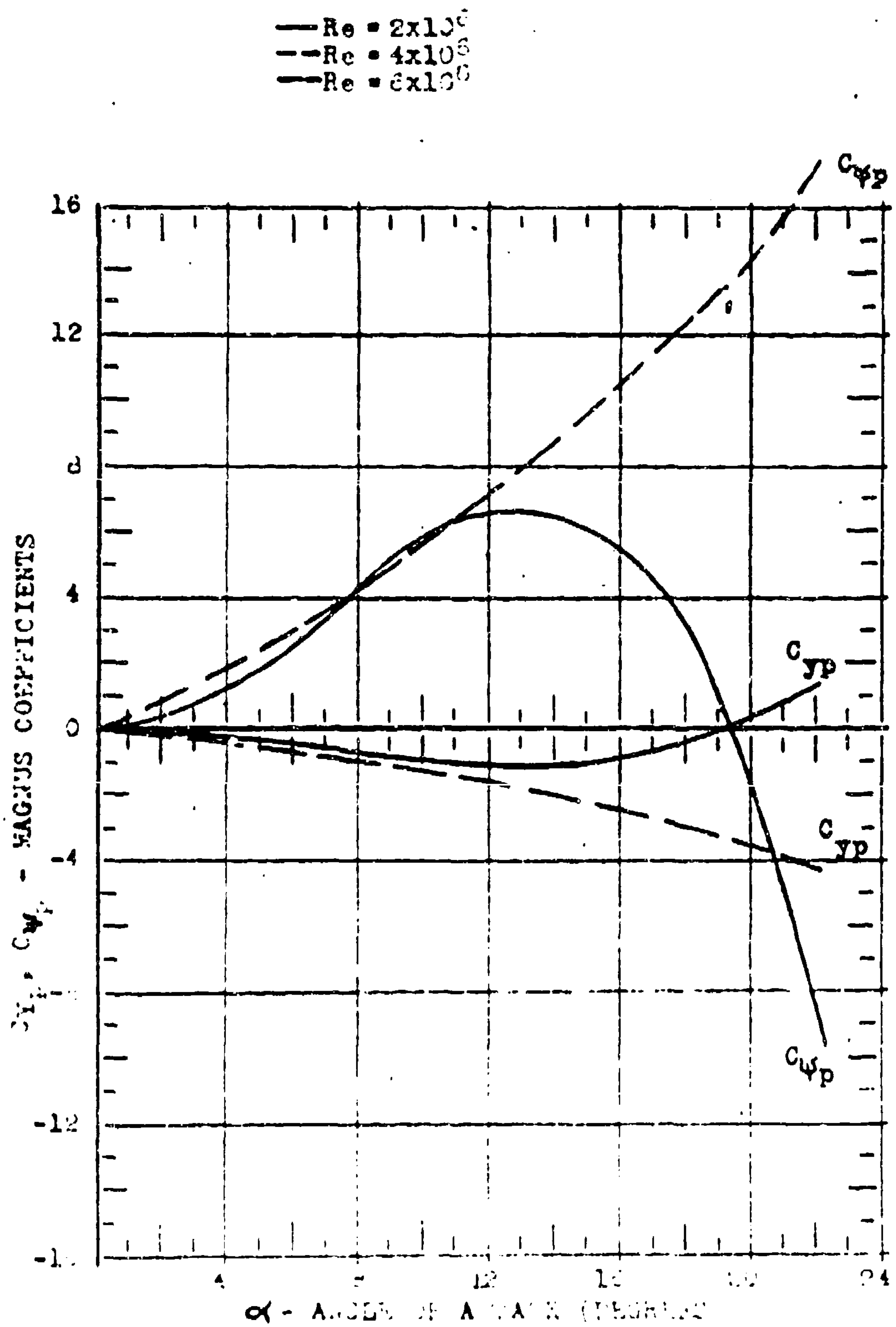
VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

M = 1.20



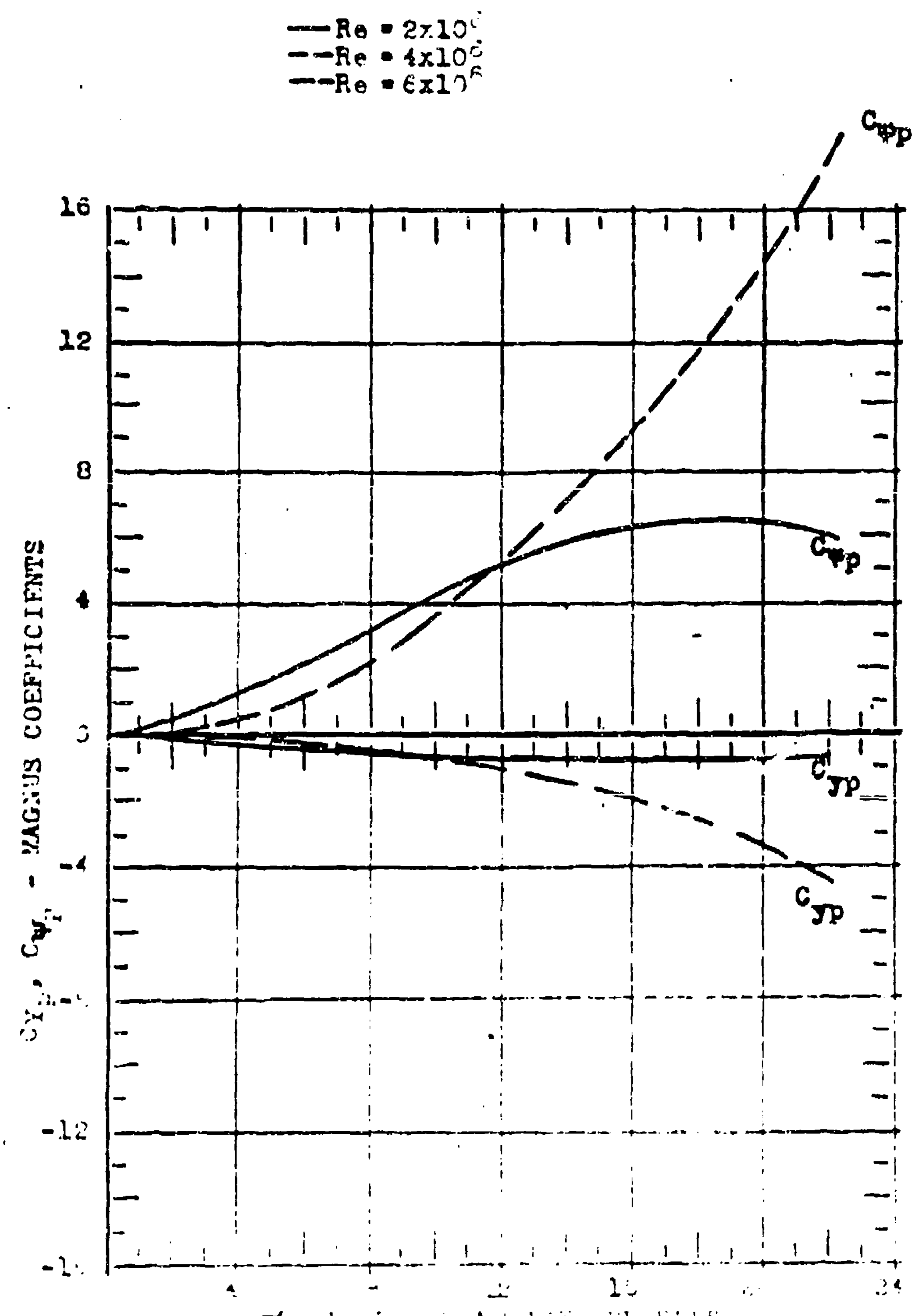
VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

M = 1.19



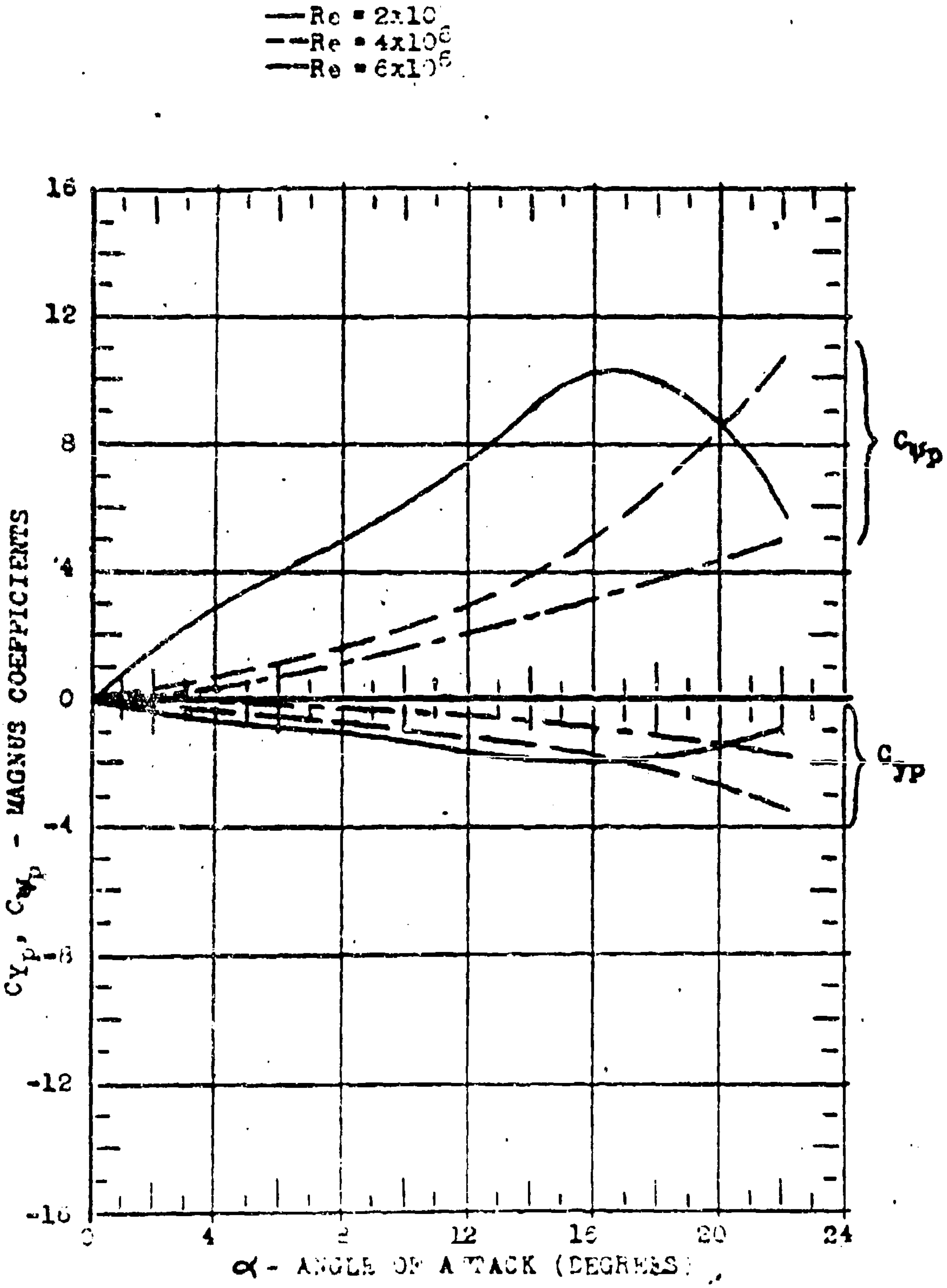
VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

M = 1.00



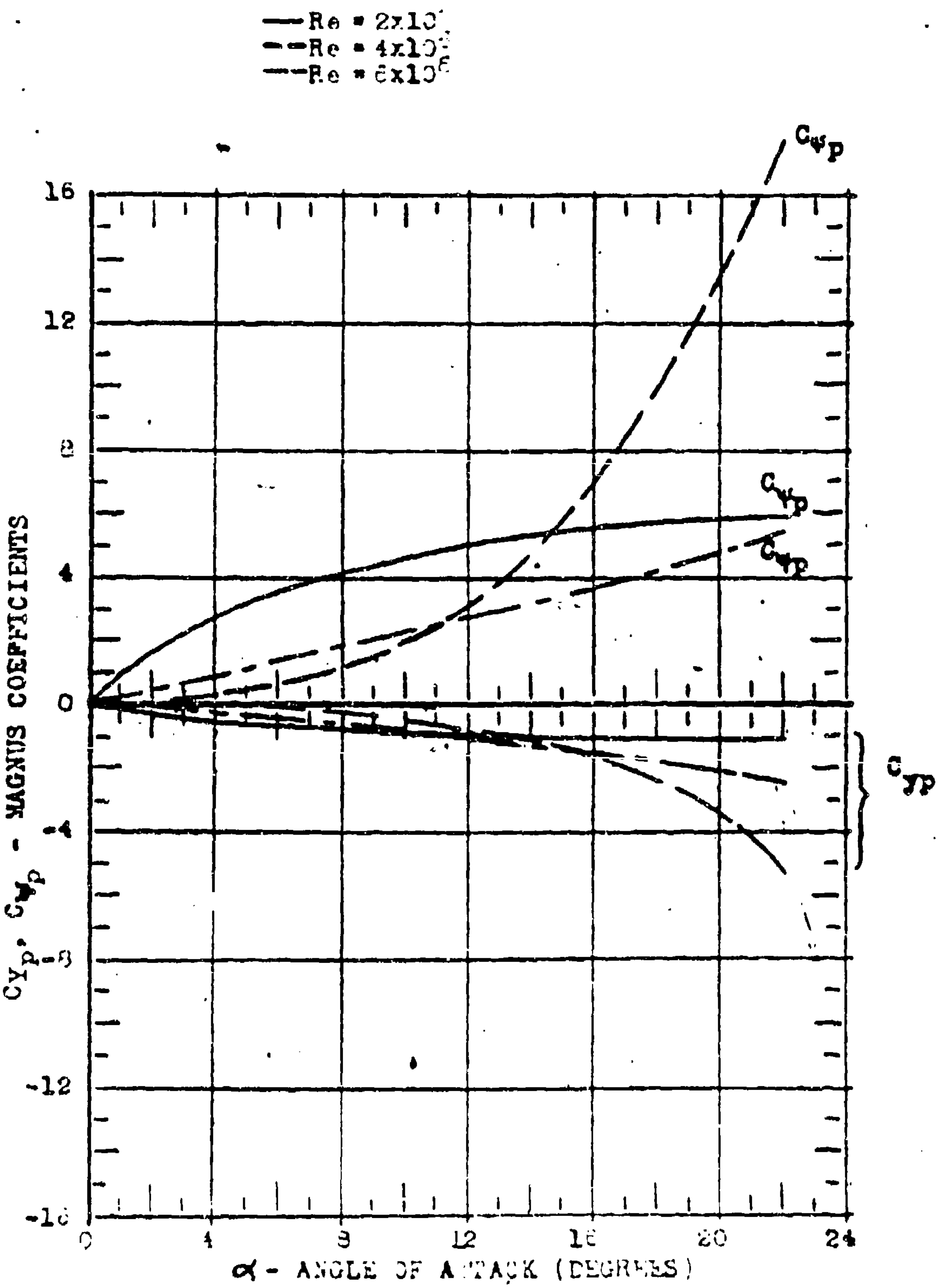
VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

M = 0.95

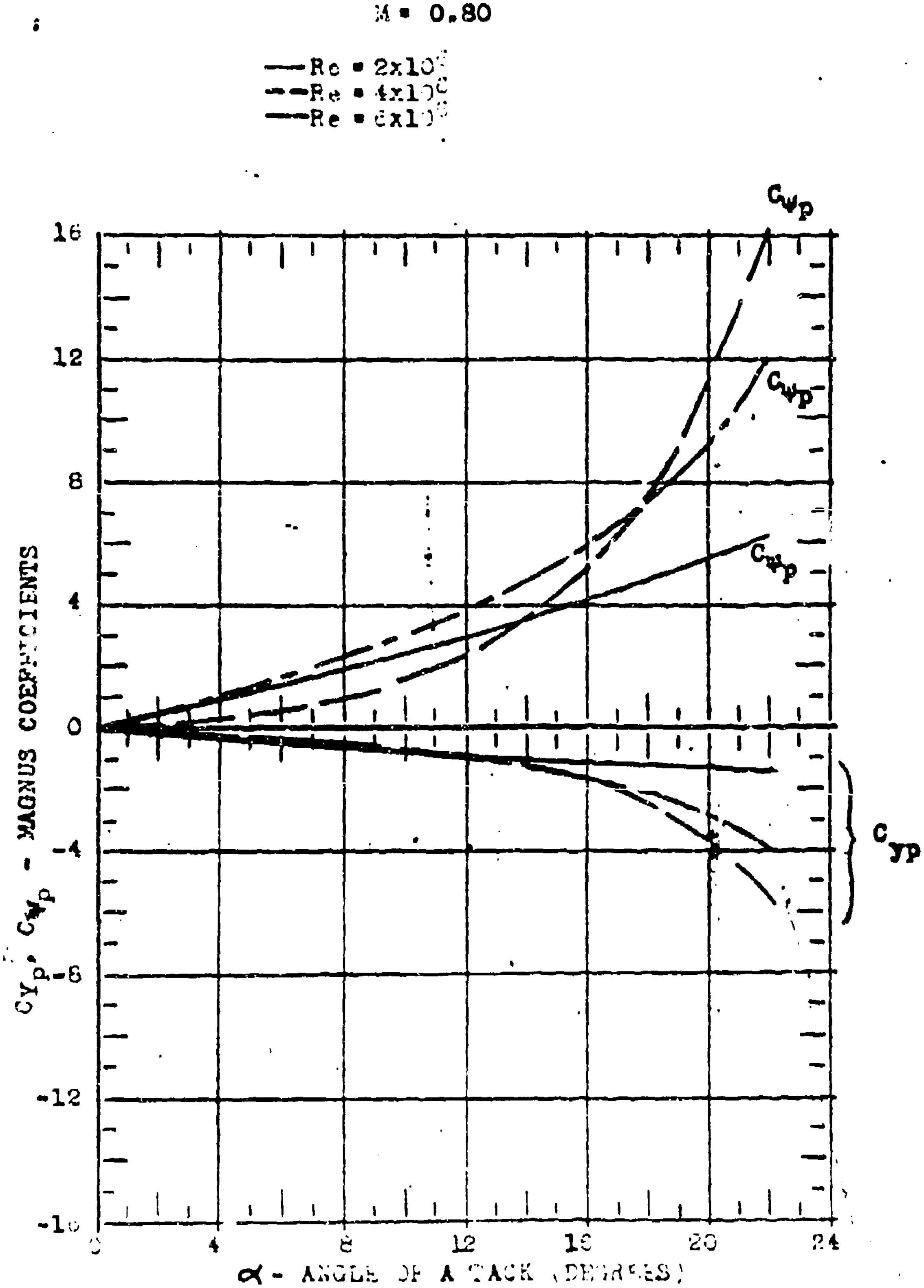


VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

M = 0.90

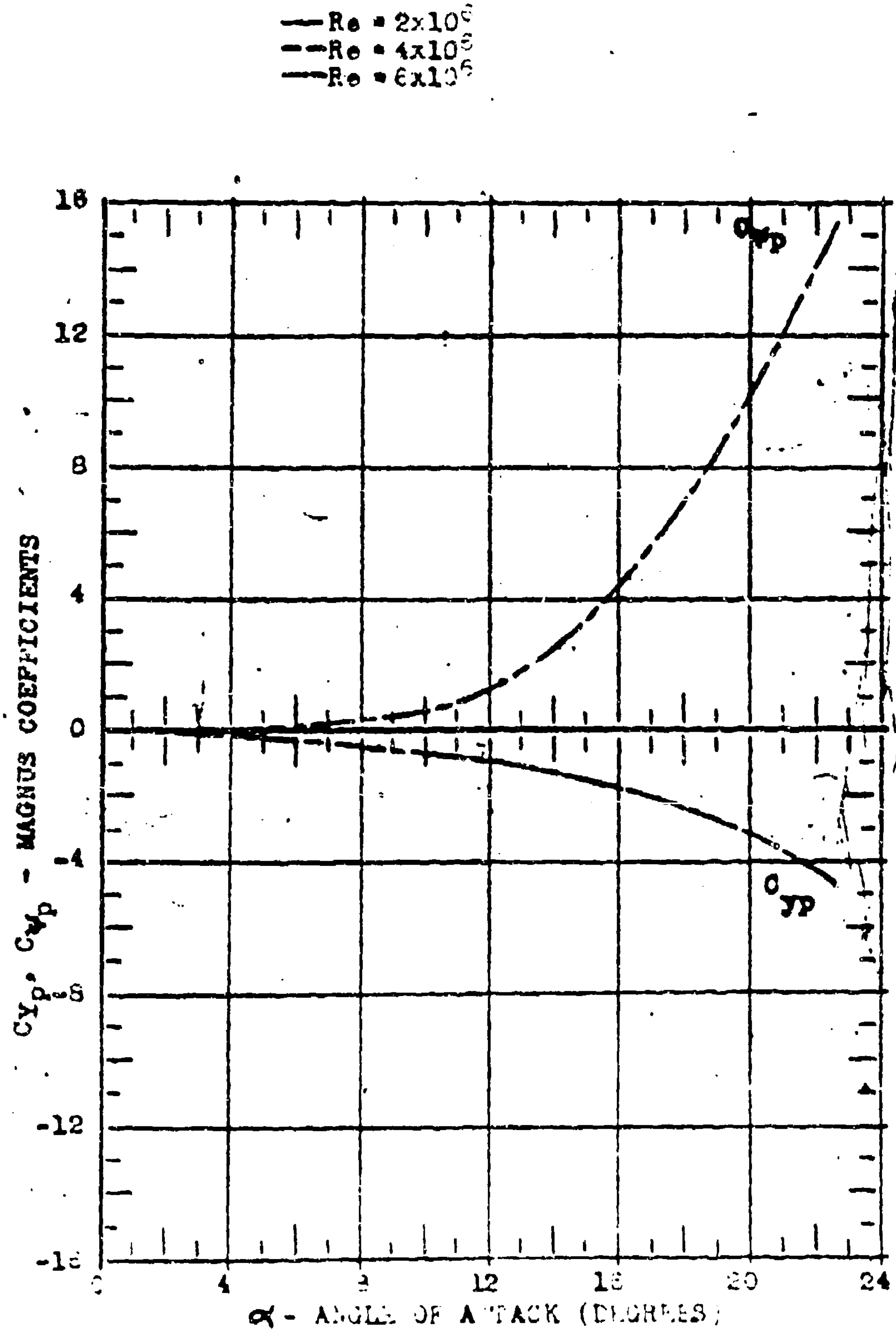


VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK



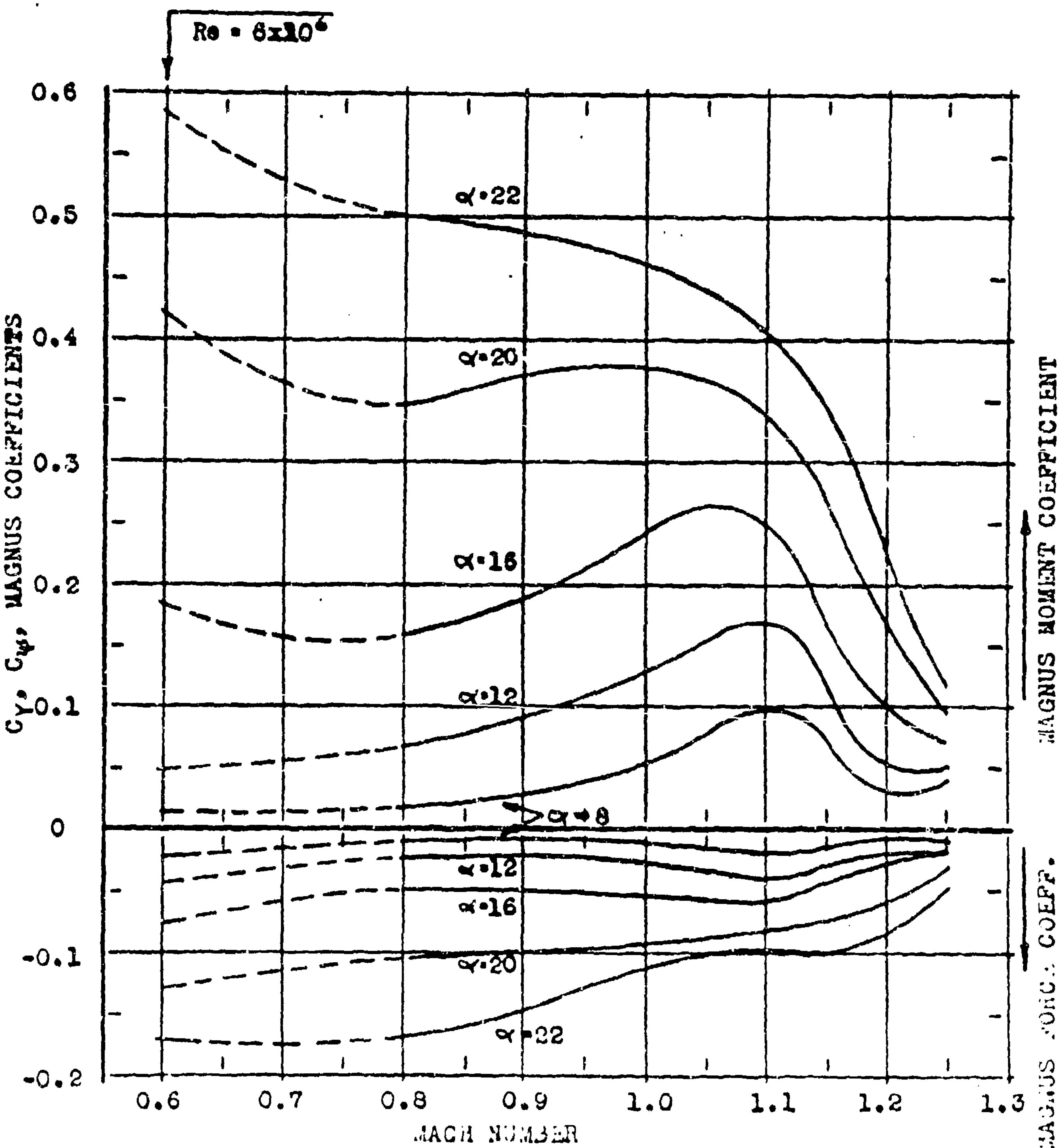
VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH ANGLE OF ATTACK

M = 0.60



VARIATION OF MAGNUS FORCE AND MOMENT COEFFICIENT WITH MACH NUMBER FOR MODEL REYNOLDS NUMBER OF 4×10^6

$p = 2000$ RPM



LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 1.25

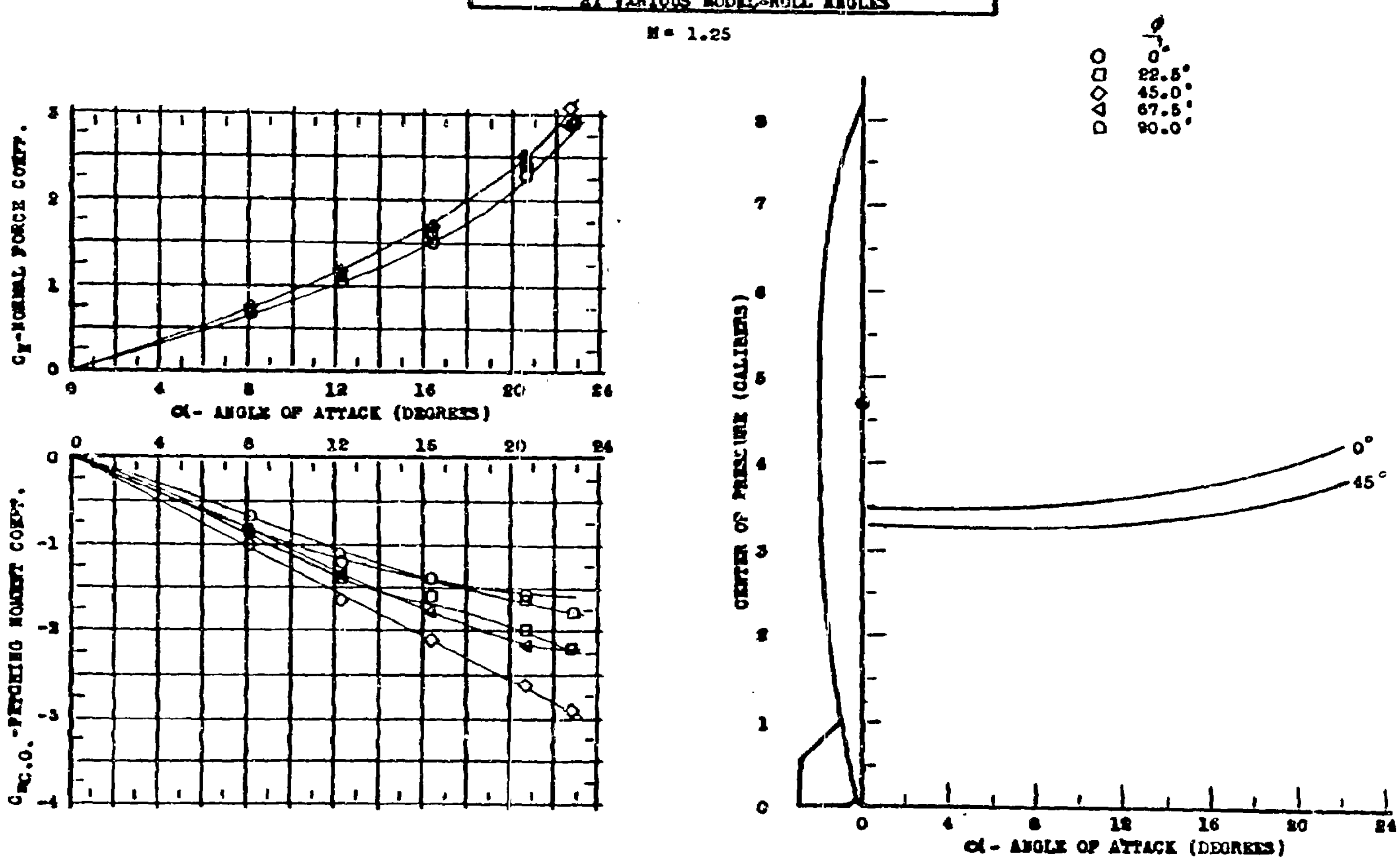


FIGURE 12

LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 1.25

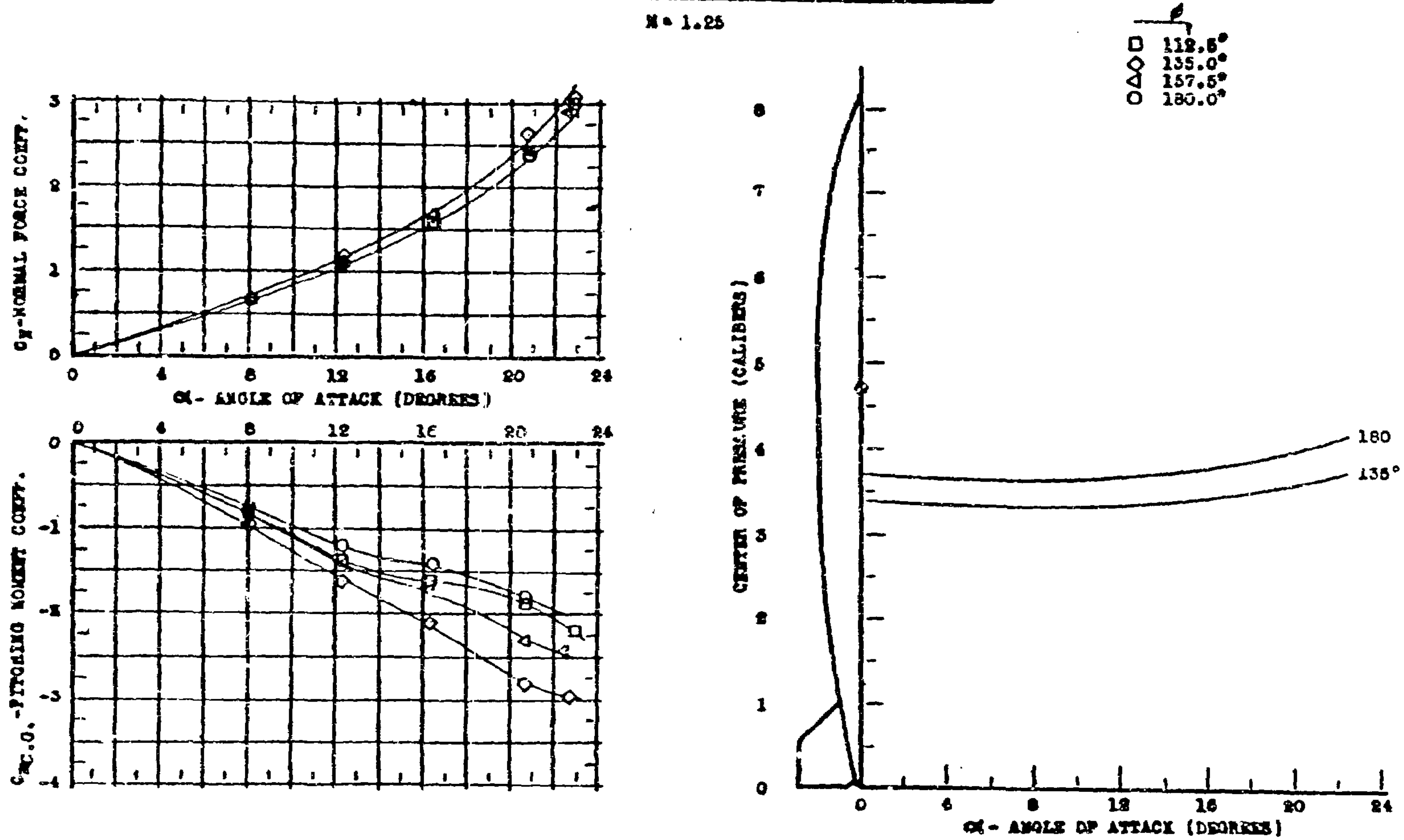


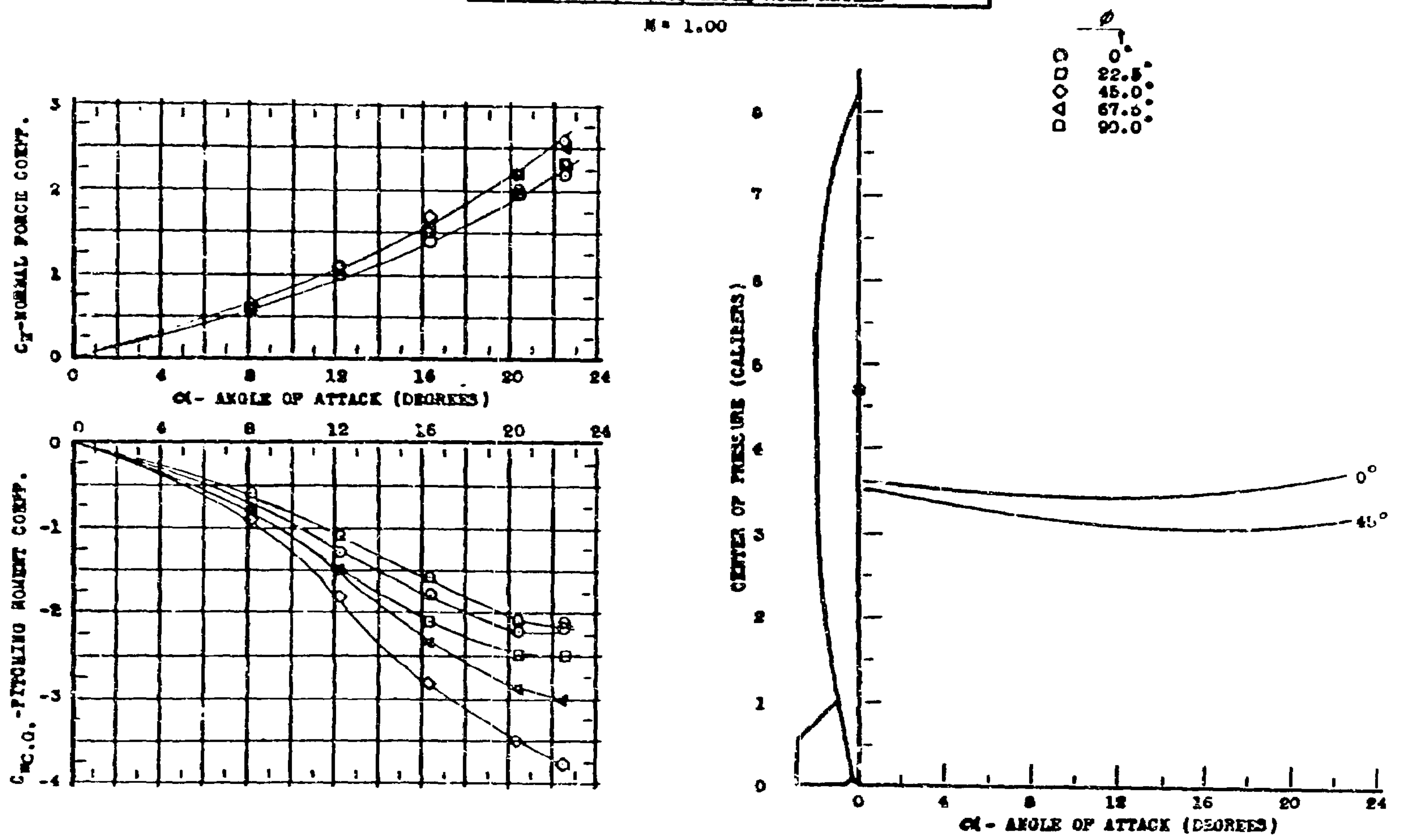
FIGURE 33

CONFIDENTIAL
NAVORD REPORT 4329

LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 1.00



CONFIDENTIAL

FIGURE 14

LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 1.00

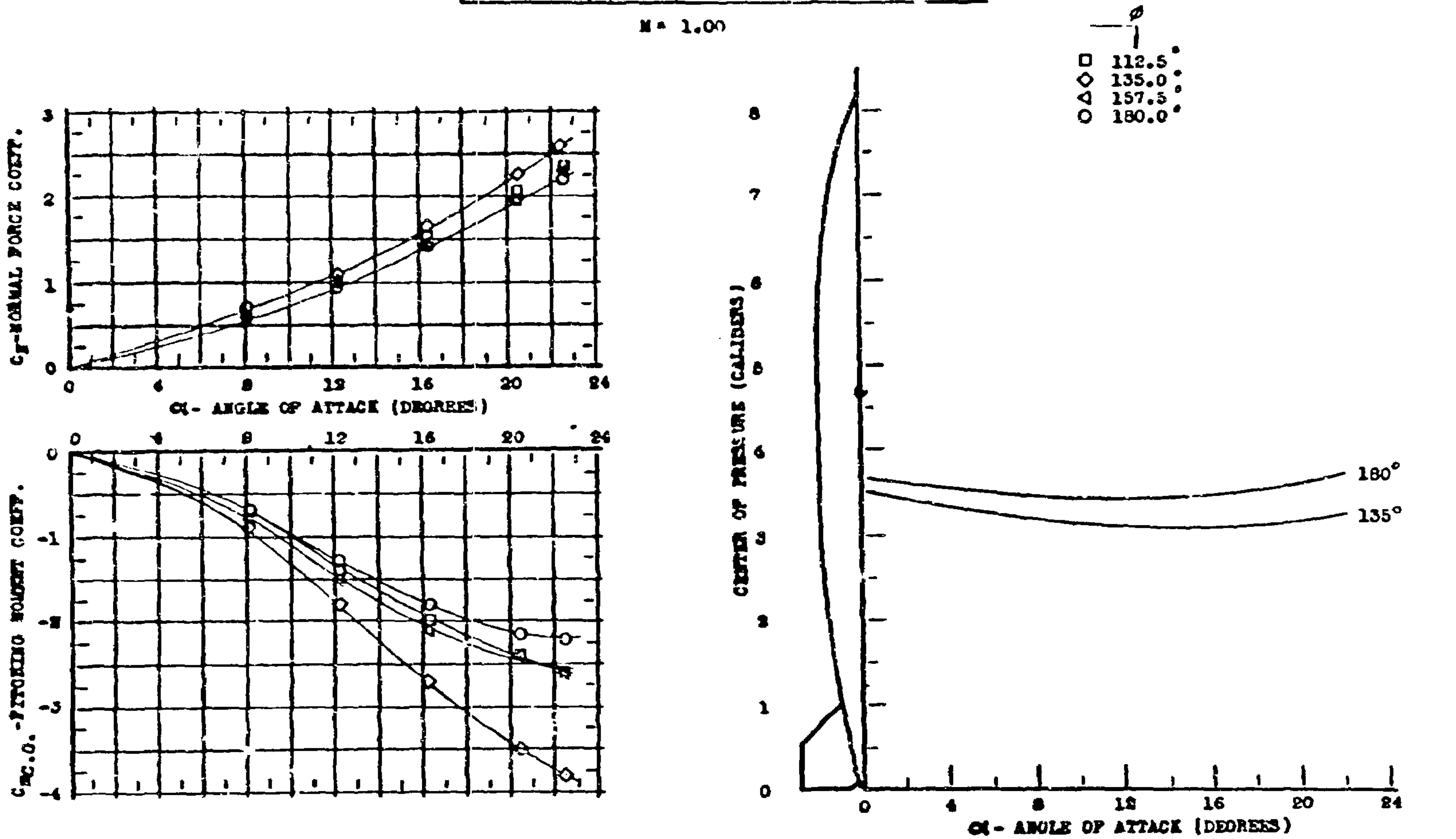
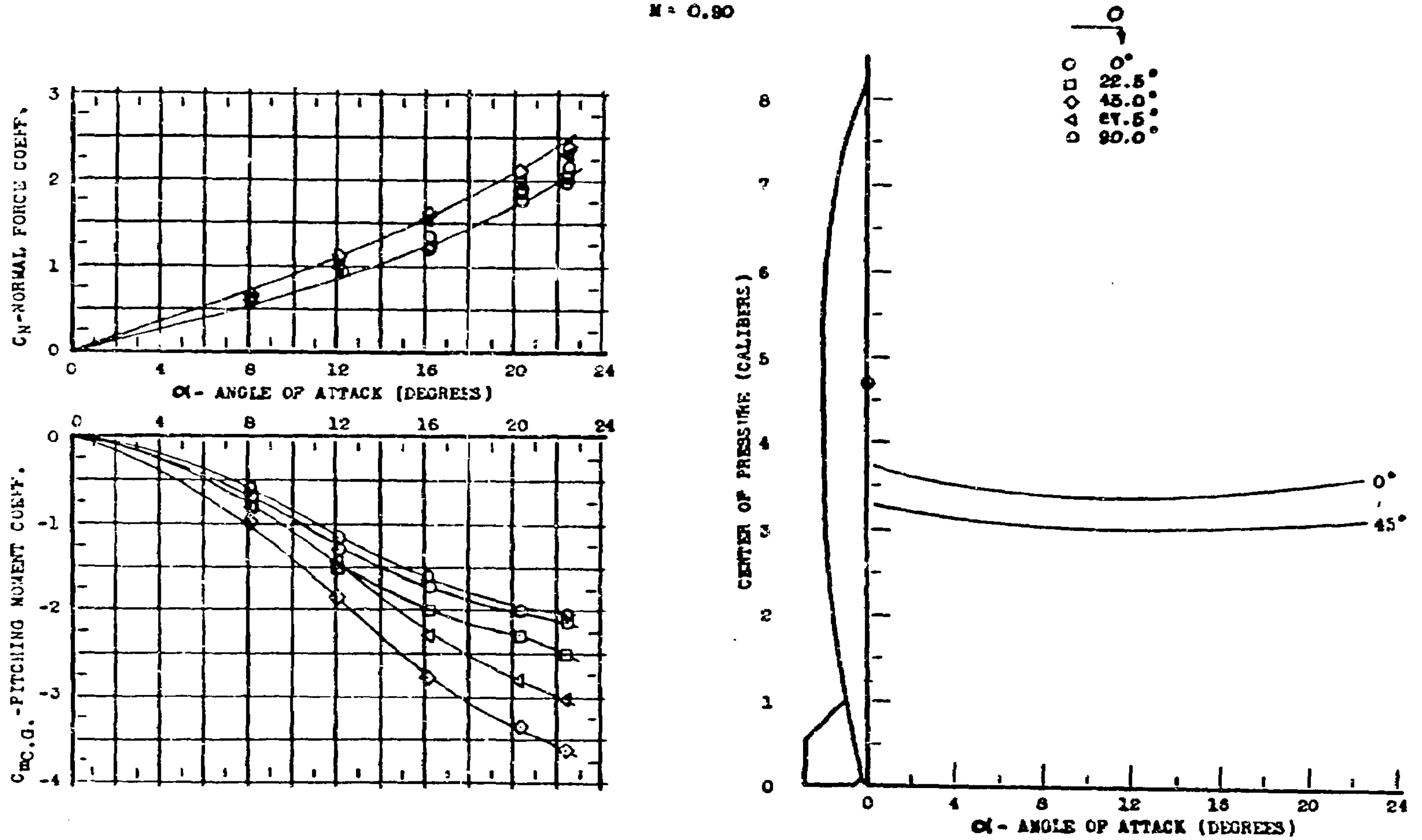


FIGURE 15

LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

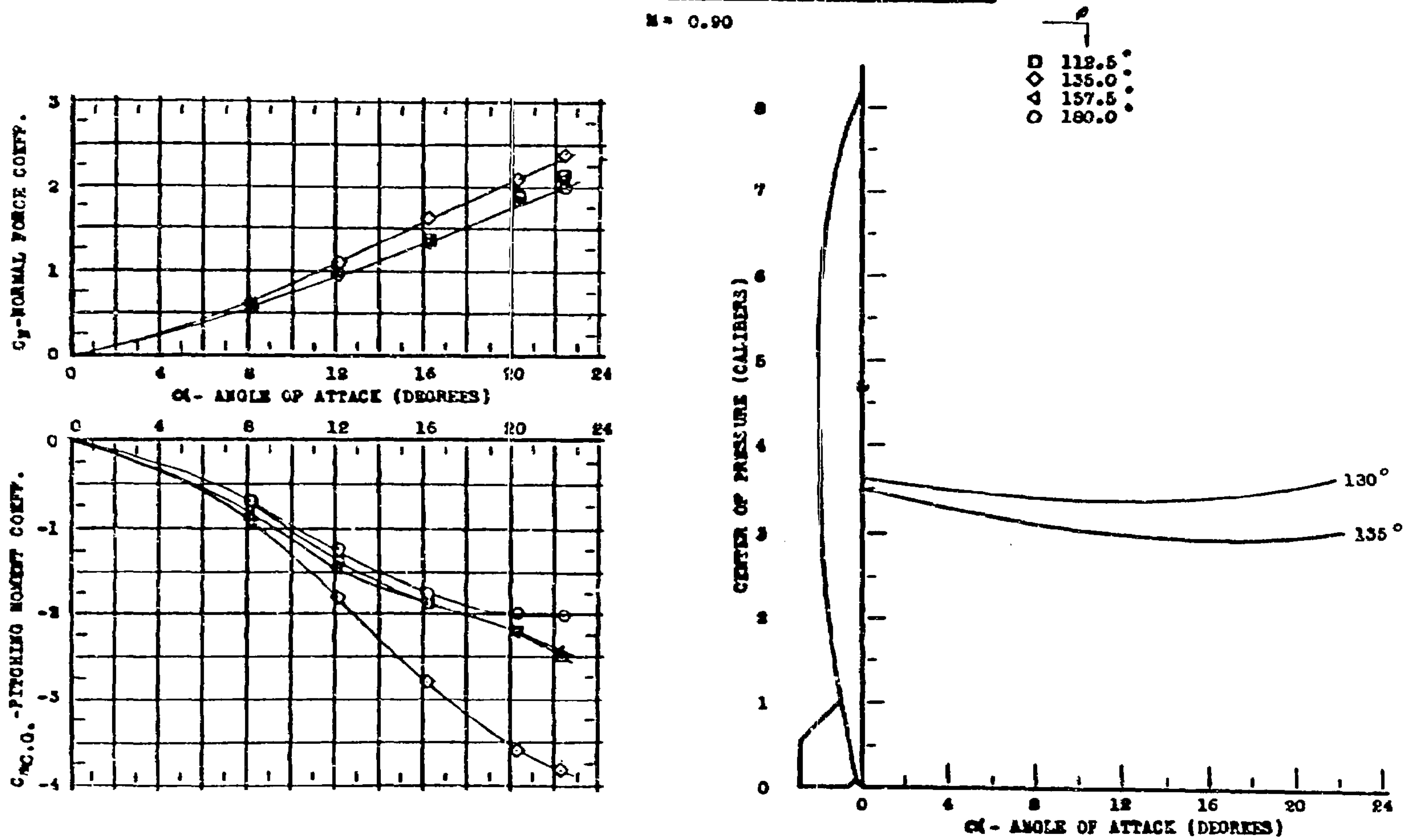
M = 0.90



LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 0.90



LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 0.60

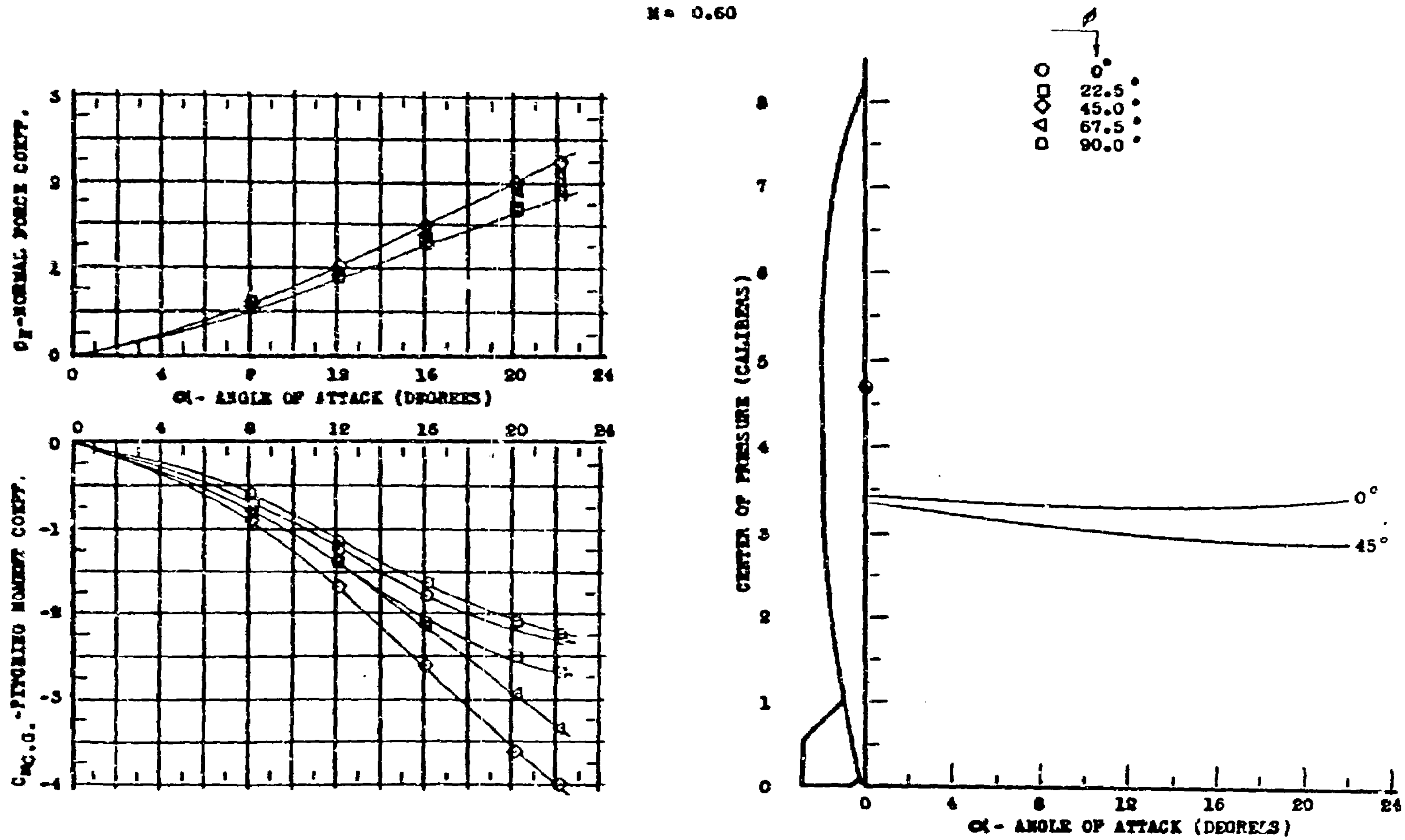


FIGURE 18

LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AT VARIOUS MODEL-ROLL ANGLES

M = 0.60

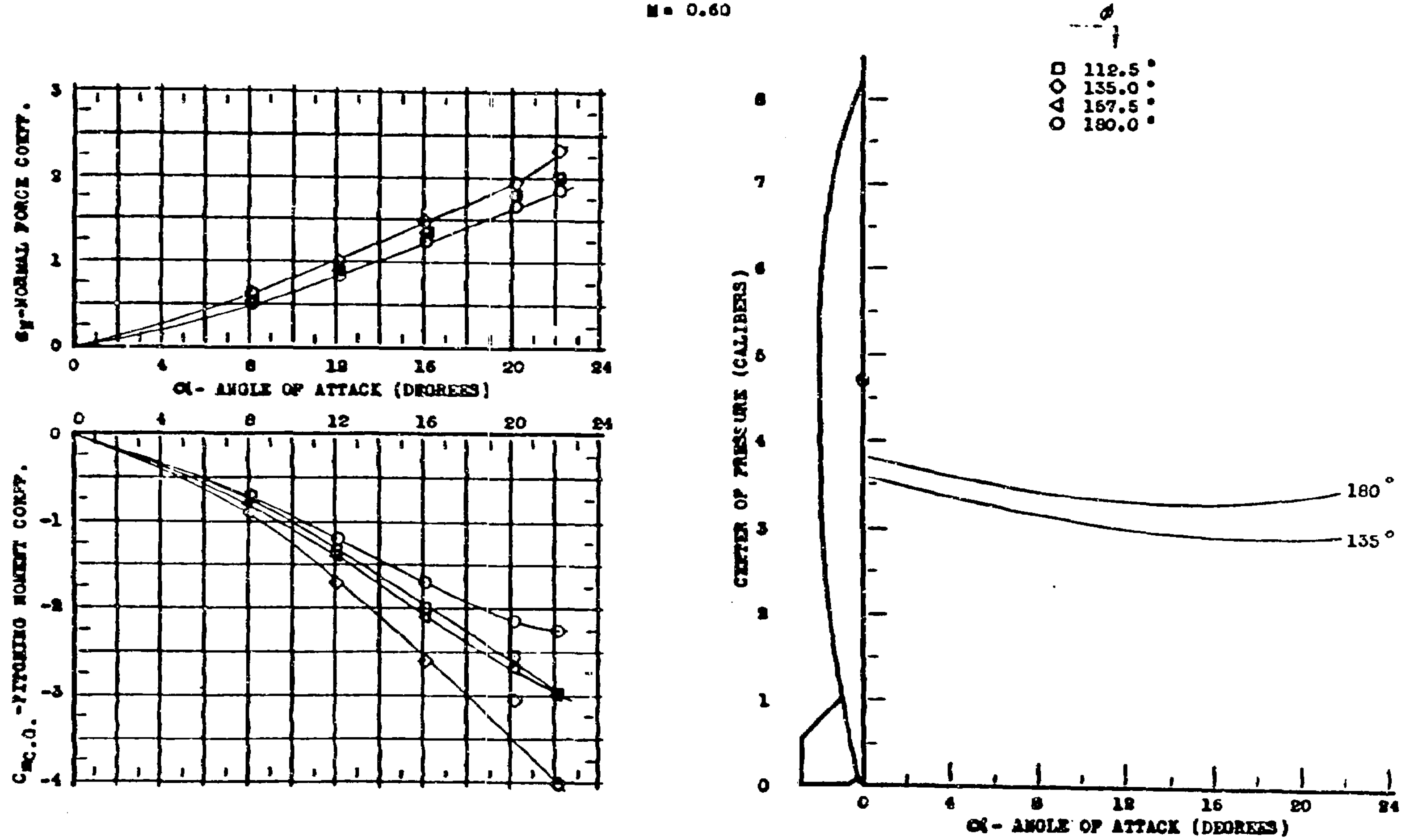
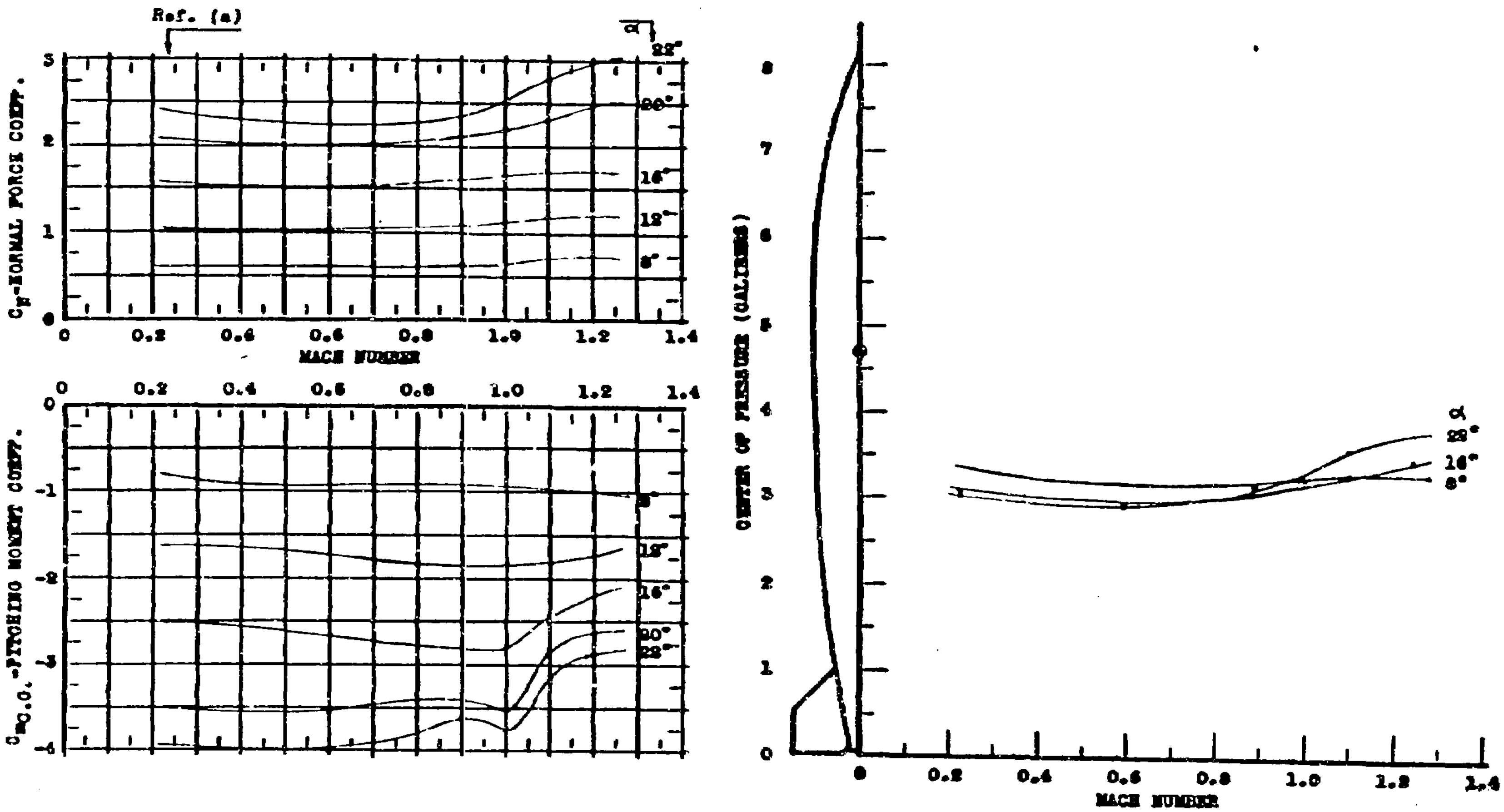


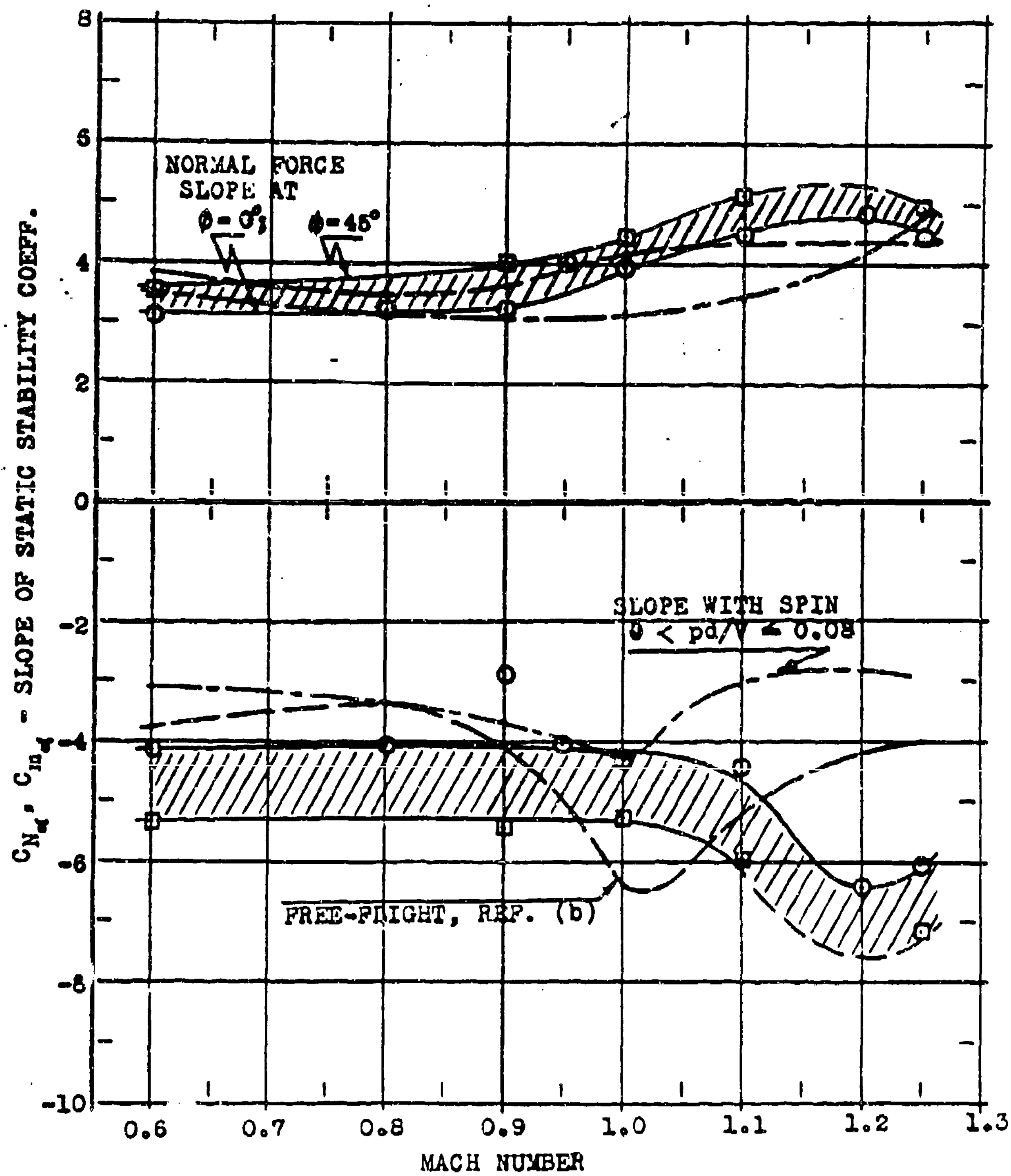
FIGURE 19

LOW-DRAG BOMB

VARIATION OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT WITH MACH NUMBER AT β=45°



COMPARISON OF NORMAL FORCE AND PITCHING MOMENT COEFFICIENT SLOPES FROM WIND TUNNEL AND FREE-FLIGHT RANGE MEASUREMENTS



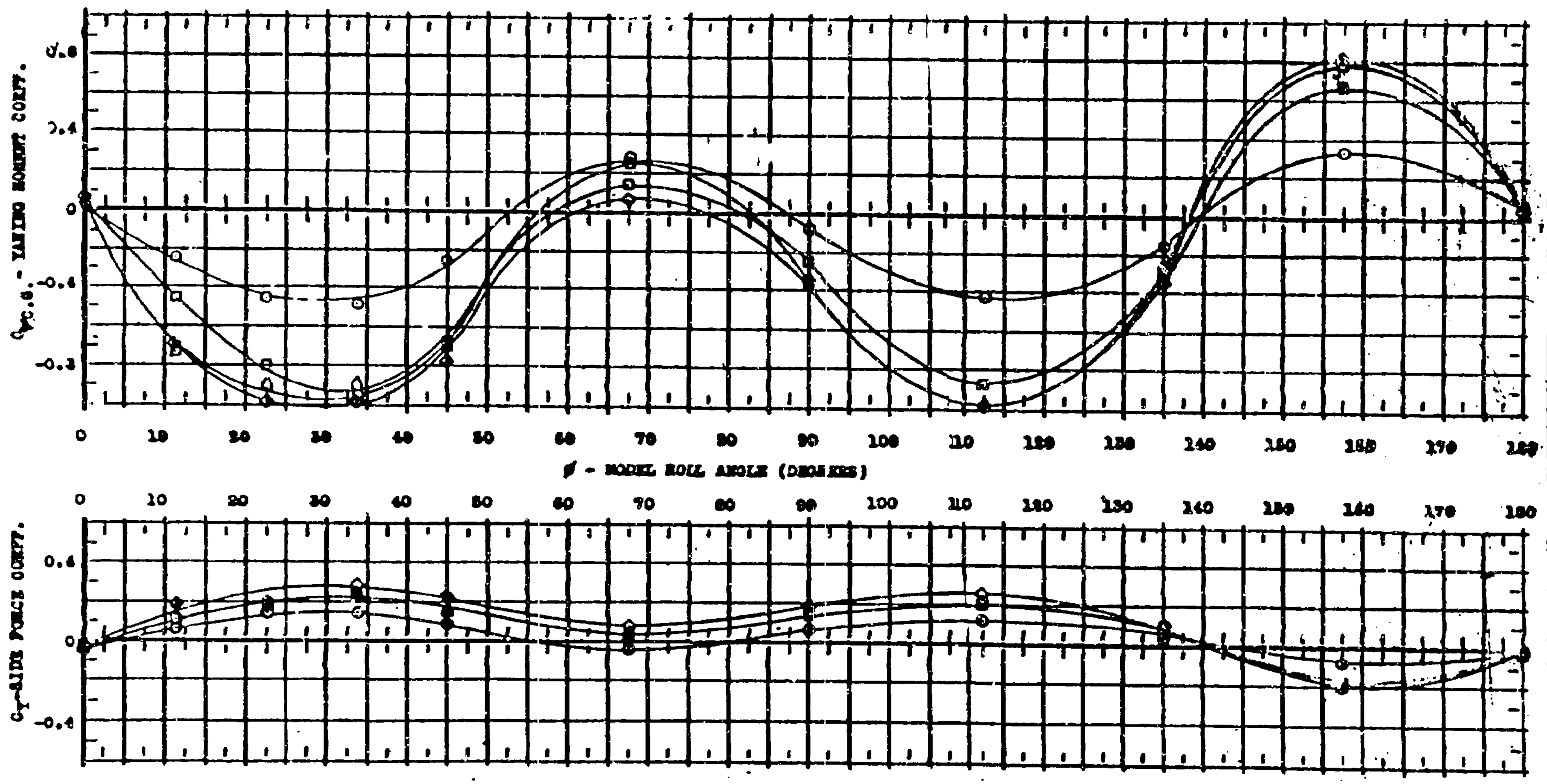
CONFIDENTIAL
NAVORD REPORT 4349

LOW-DRAG BOMB

VARIATION OF SIDE FORCE AND YAWING MOMENT COEFFICIENT WITH MODEL ROLL ANGLE AT VARIOUS ANGLES OF ATTACK

M = 1.25

	α
○	12°
□	16°
◇	20°
△	22°



CONFIDENTIAL

FIGURE 2?

LOW-DRAG BOMB

VARIATION OF SIDE FORCE AND YAWING MOMENT COEFFICIENT WITH MODEL ROLL ANGLE AT VARIOUS ANGLES OF ATTACK

M = 1.00

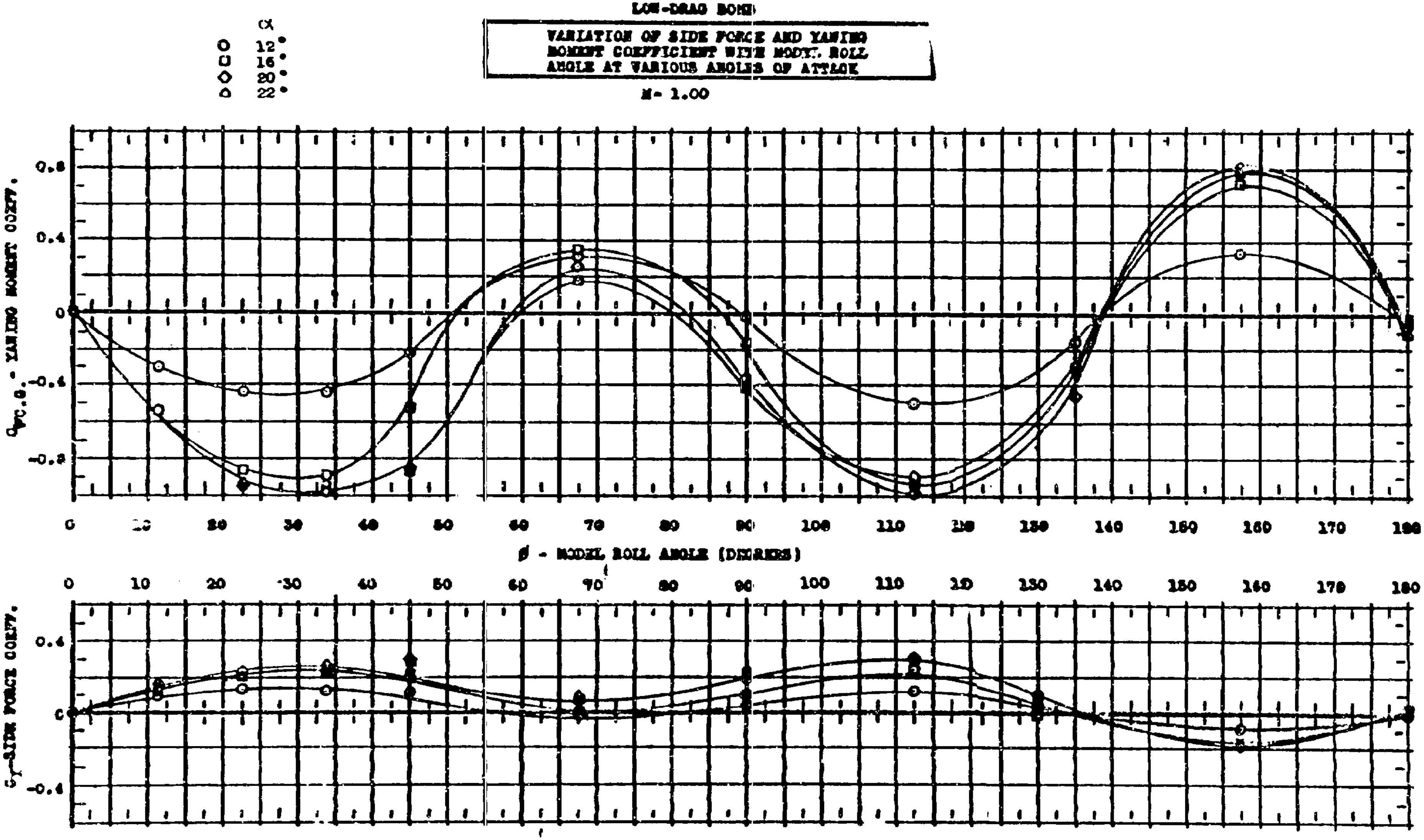


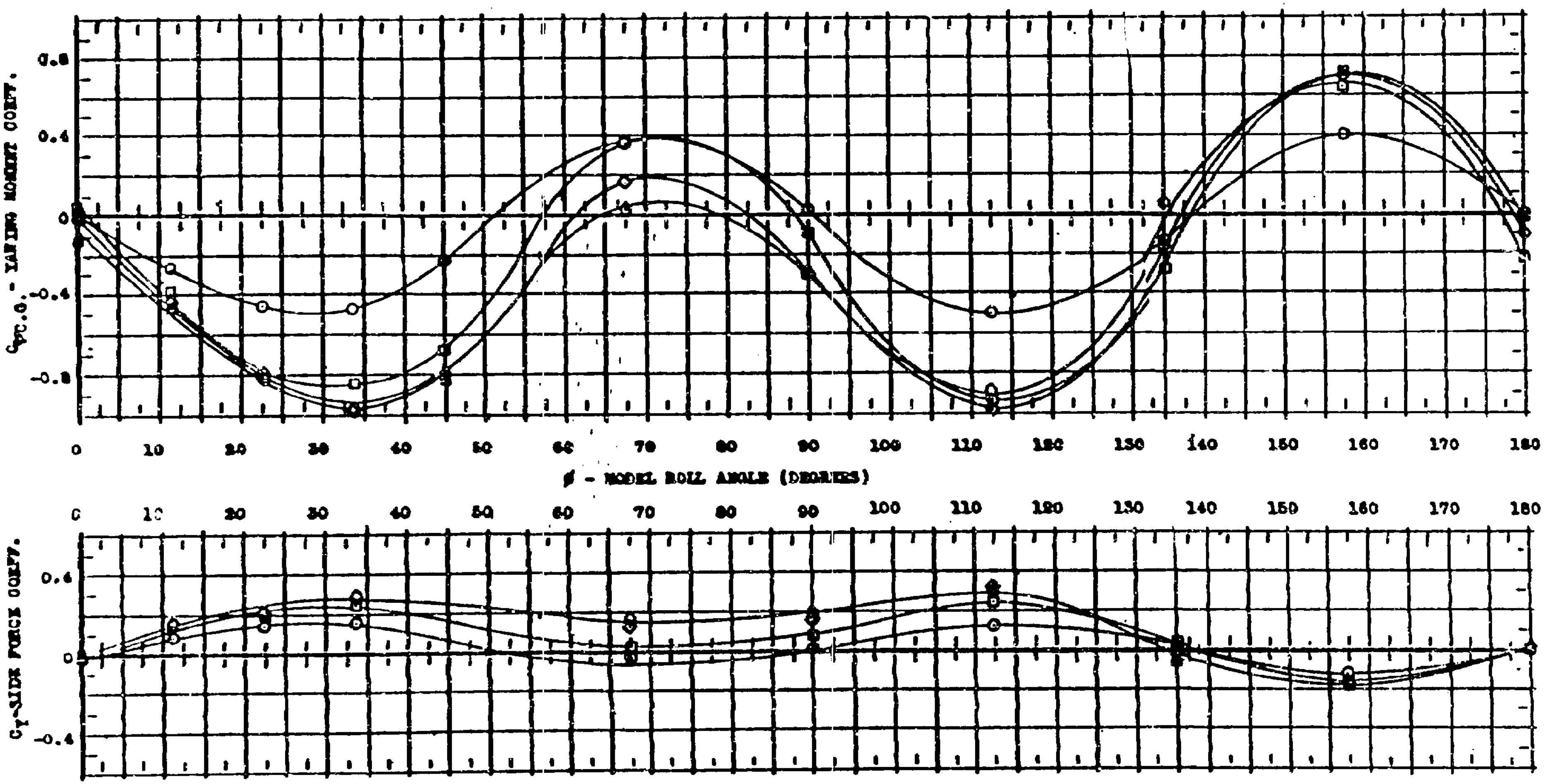
FIGURE 25

LOW-DRAG BOMB

VARIATION OF SIDE FORCE AND YAWING MOMENT COEFFICIENT WITH MODEL ROLL ANGLE AT VARIOUS ANGLES OF ATTACK

M = 0.90

	α
○	12°
□	16°
◇	20°
△	22°



LOW-DRAG BOMB

VARIATION OF SIDE FORCE AND YAWING MOMENT COEFFICIENT WITH MODEL ROLL ANGLE AT VARIOUS ANGLES OF ATTACK

M = 0.60

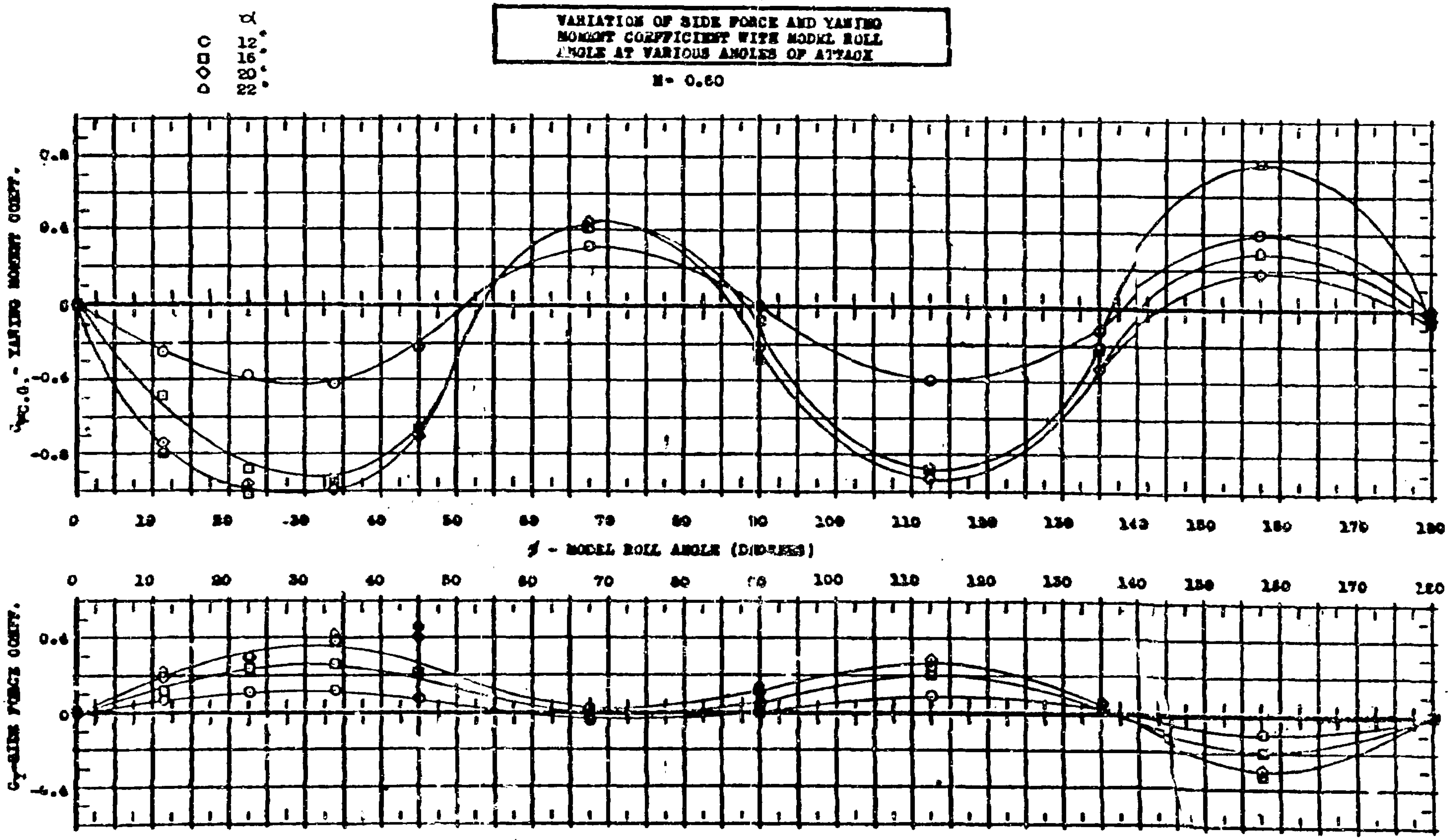


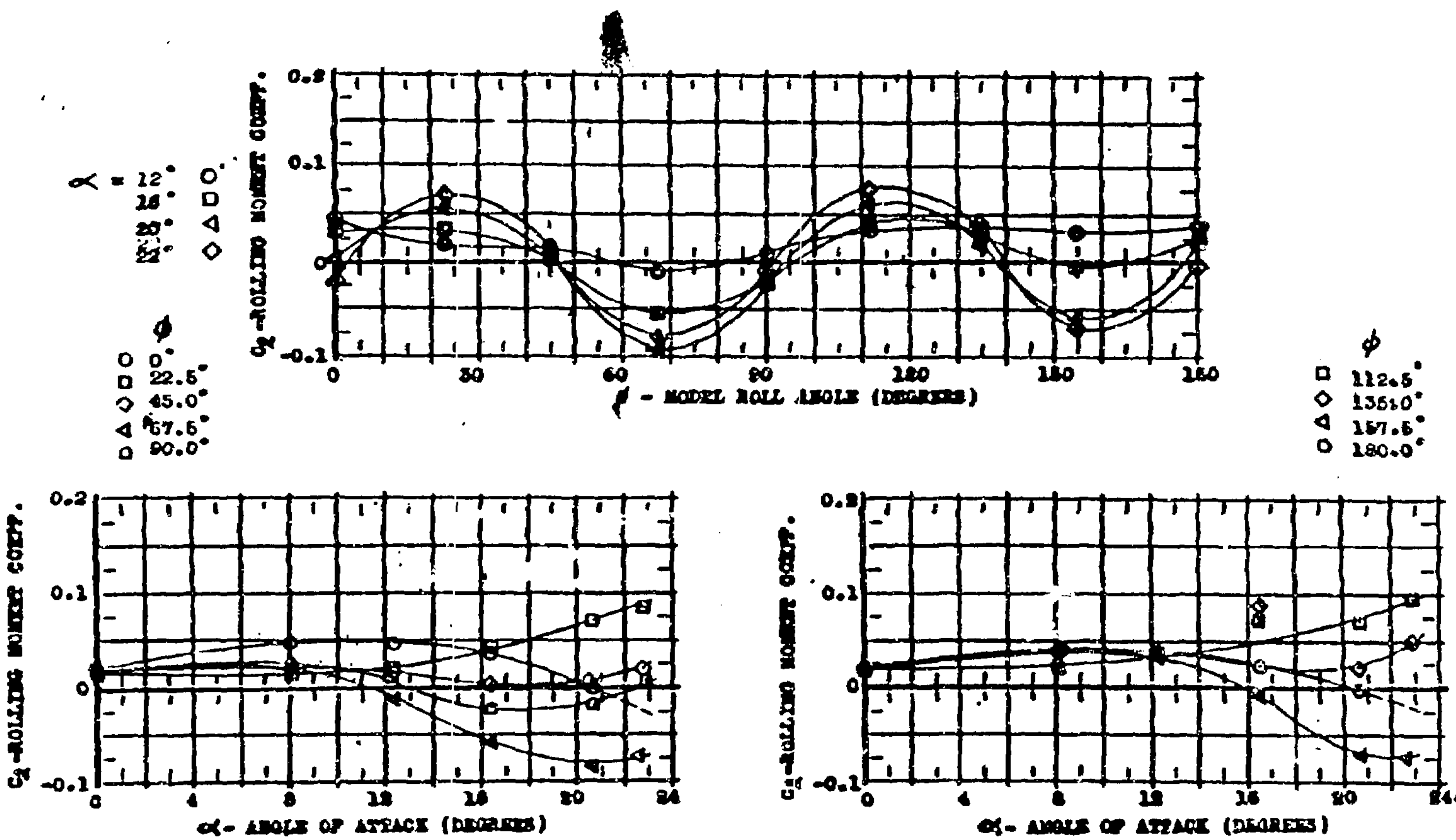
FIGURE 25

CONFIDENTIAL
NAVORD REPORT 4329

LOW-DRAG BOMB

VARIATION OF ROLLING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

M = 1.25



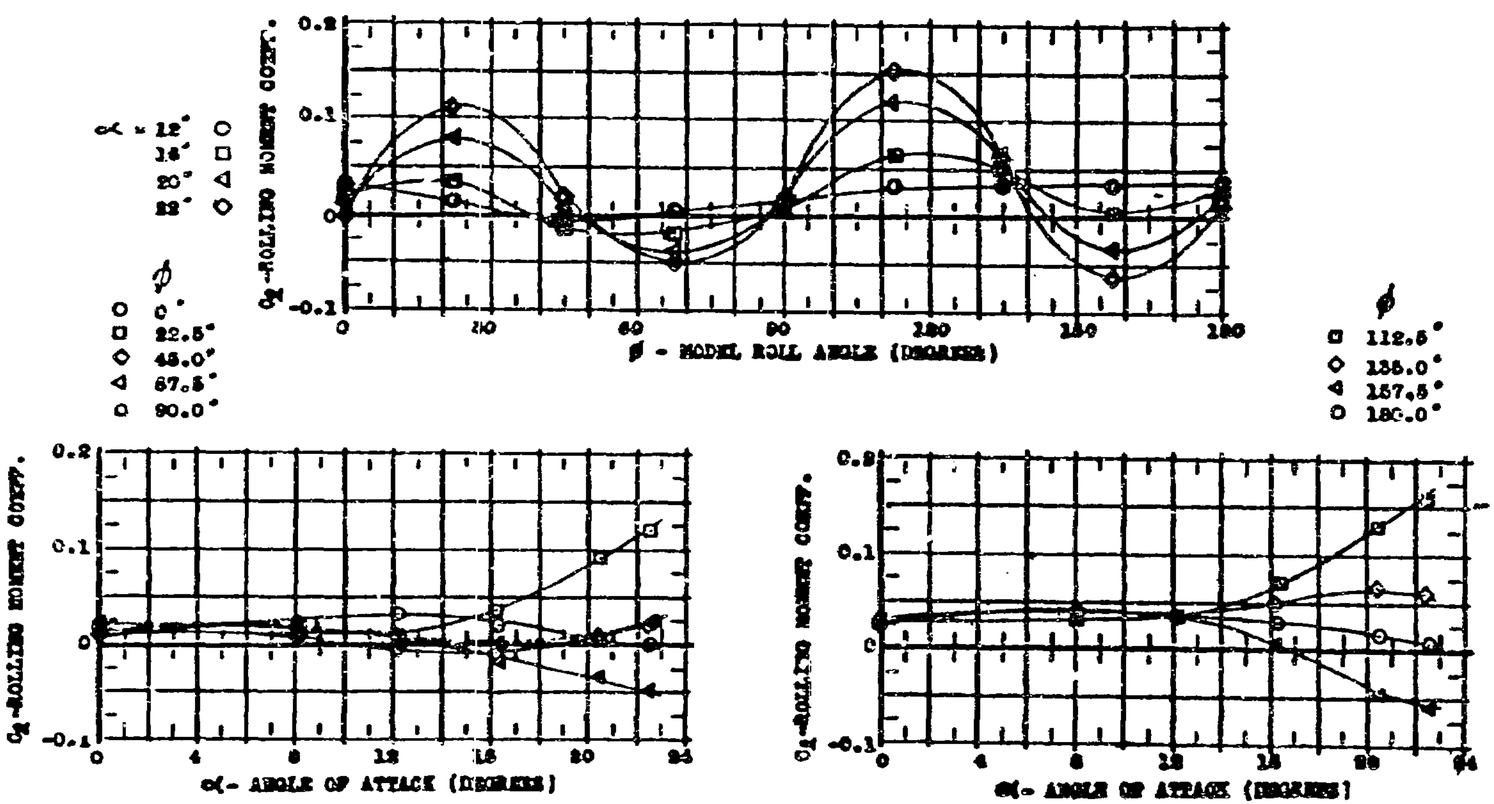
CONFIDENTIAL

FIGURE 26

LOW-DRAG BOMB

VARIATION OF ROLLING MOMENT COEFFICIENT WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

M = 1.00

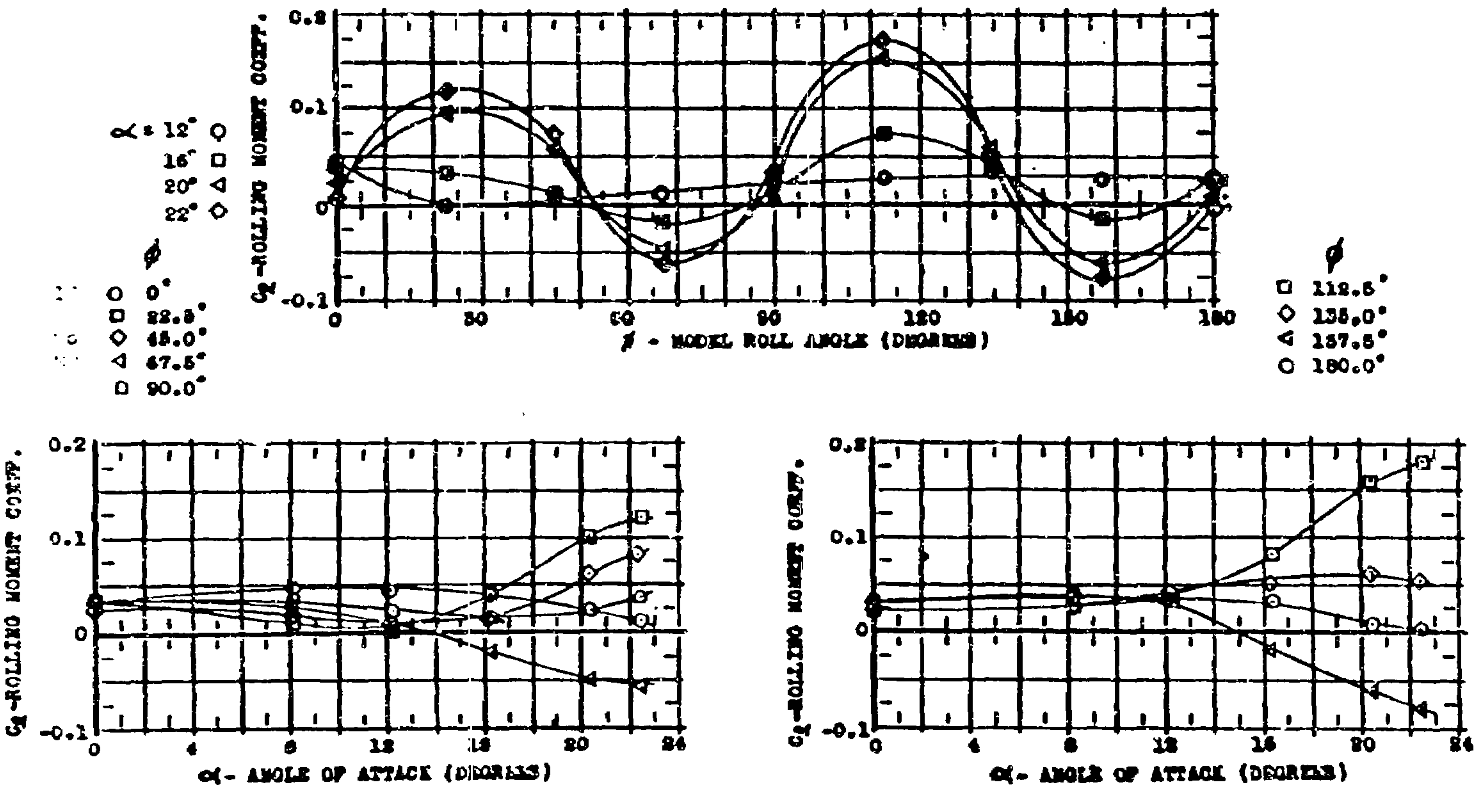


CONFIDENTIAL
NAVORD REPORT 4329

LOW-DRAG BOMB

VARIATION OF ROLLING MOMENT COEFFICIENT
WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

M = .90



CONFIDENTIAL

FIGURE

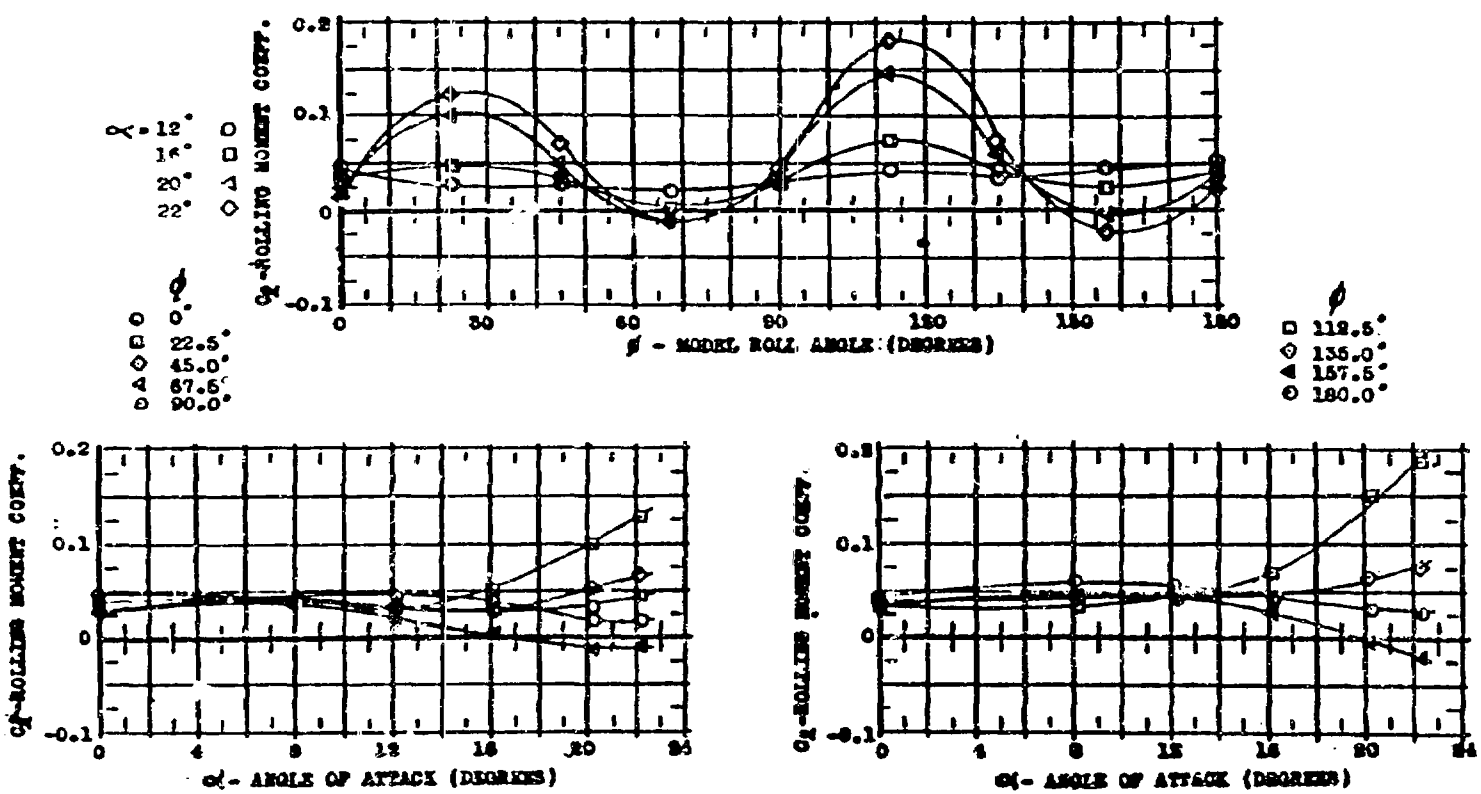
[redacted]

NAVORD REPORT 4329

LOW-DRAG BOMB

VARIATION OF ROLLING MOMENT COEFFICIENT
WITH ANGLE OF ATTACK AND MODEL ROLL ANGLE

M = .60

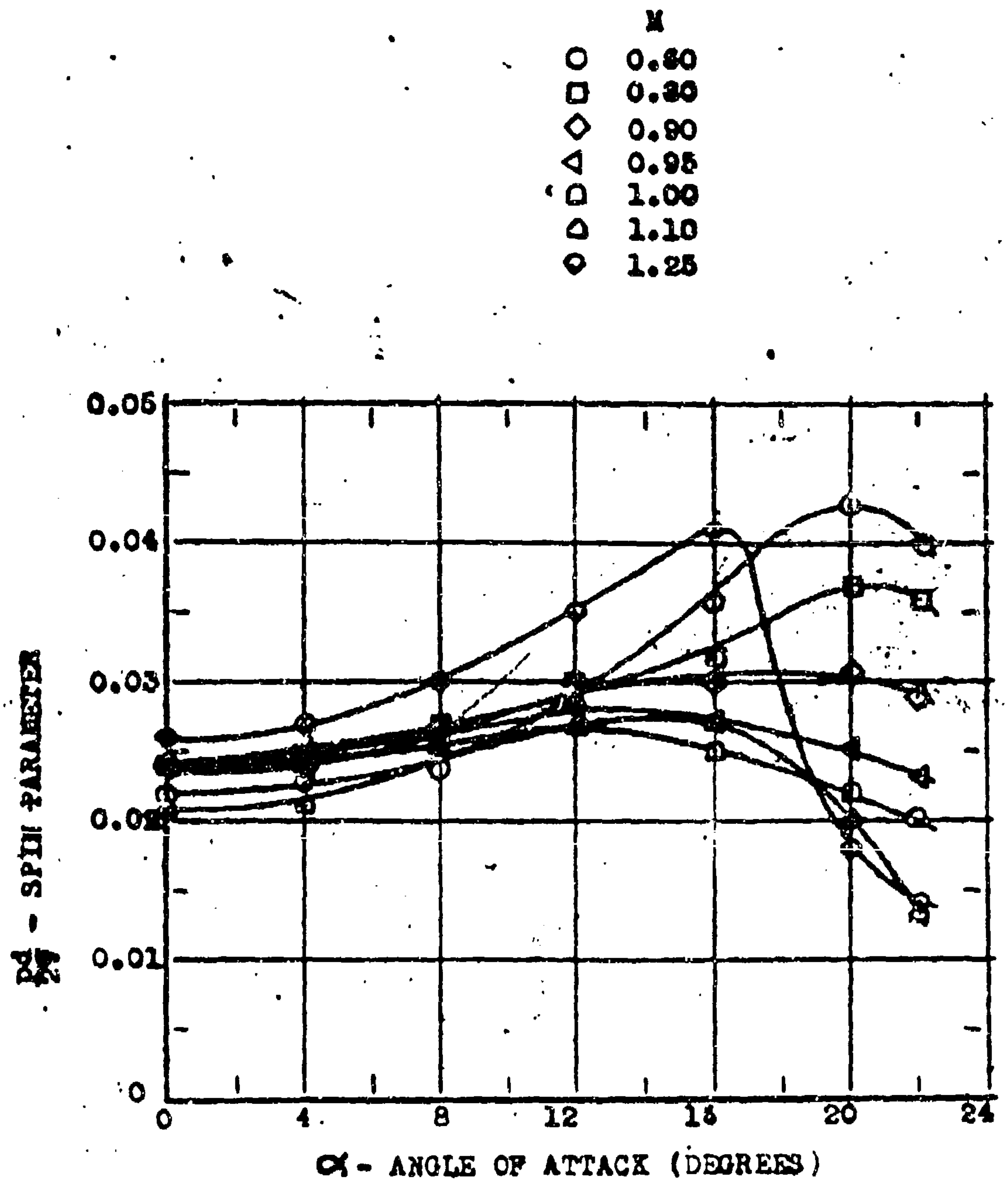


[redacted]

[illegible] 29

LOW-DRAG BOMB

VARIATION OF SPIN PARAMETER, pd/2V, WITH ANGLE OF ATTACK AT VARIOUS FREE-STREAM MACH NUMBERS



[redacted]

FIGURE 38

LOW-DRAG BOMB

VARIATION OF DRAG COEFFICIENT WITH MACH NUMBER AT ZERO DEGREE ANGLE OF ATTACK

○ $Re = 4 \times 10^6$, LUGS ON (BASE DRAG COMPONENT REMOVED)
□ $Re = 4 \times 10^6$, LUGS OFF (BASE DRAG COMPONENT REMOVED)
— $1.52 \times 10^6 \leq Re \leq 3.45 \times 10^6$ (FREE-FLIGHT, REF (b))

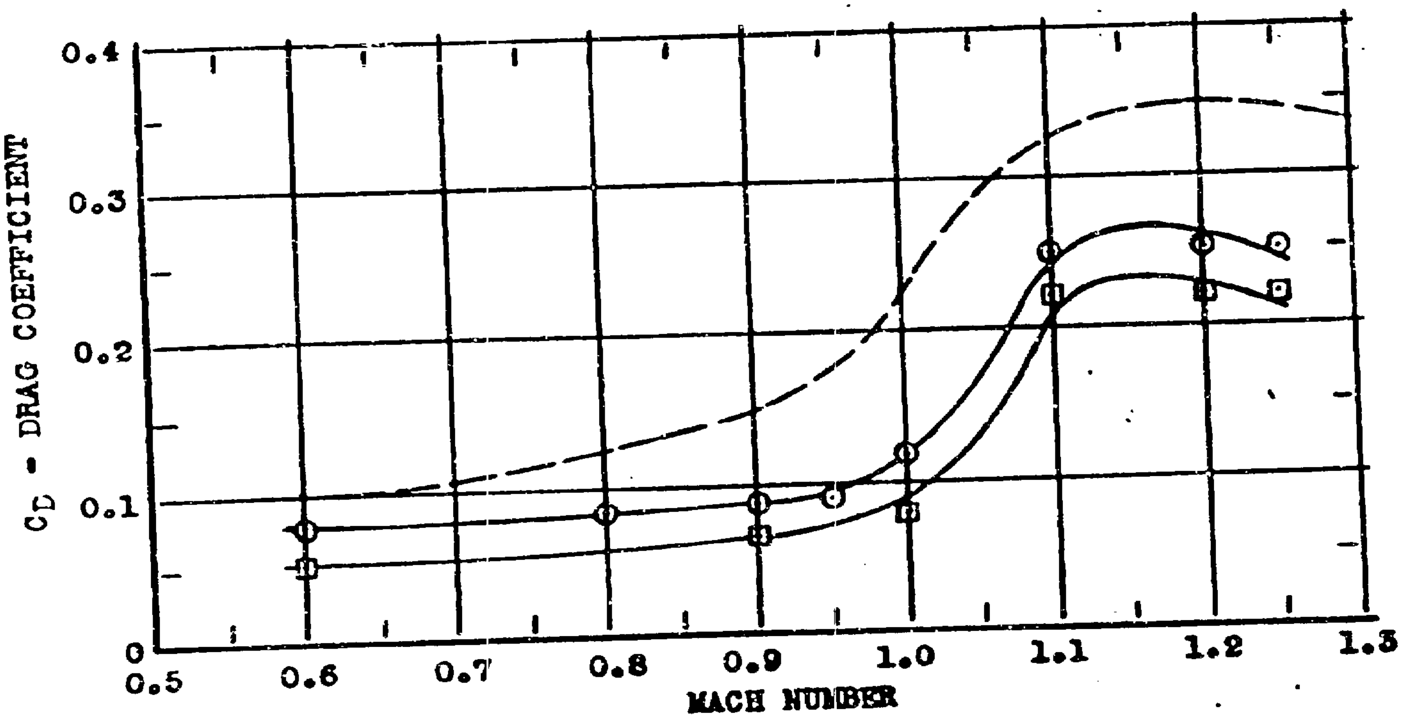


FIGURE 31

External Distribution List

	No. of Copies
Chief, Bureau of Ordnance Department of the Navy Washington 25, D. C. Attn: Re03 Attn: Re4d	 1 1
Chief, BuAer Washington 25, D. C. Attn: TD-414	 4
Commander, U. S. NOTS China Lake, California Attn: Technical Library Attn: Code 503	 1 1
Officer in Charge, NPG Dahlgren, Virginia Attn: Technical Library	 1
Office, Chief of Ordnance Washington 25, D. C. Attn: ORDTU	 1
Office of the Assistant Secretary of Defense (R and D) Room 3 E 1065, The Pentagon Washington 25, D. C. Attn: Technical Library	 2
ASTIA Document Service Center Knott Building Dayton 2, Ohio	 5